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Col C. H. Hilton, Gen Staff
Room 316 [illegible]

The PHILOSOPHY
OF
SOARING FLIGHT

H. I. Means

[illegible]

Ulevold, H I

The PHILOSOPHY
OF
SOARING FLIGHT

Inductive Results Applicable to the Art of Aeroplane Construction

By

H. I. ~~ULEVOL~~D

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I. INTRODUCTORY NOTES

1. The subject dealt with herein forms an adaptation from a larger work giving a complete theory of animal flight, elaborated in the years from 1896-1906. Few, and hardly anyone interested and competent to pass judgment, could be induced to read even an abstract of a work on so discredited a subject in those days, let alone publishers; so, for personal reasons and weighty circumstances, the matter had to be left in abeyance until the signs of the times changed.

As the title indicates, it deals with one of the least understood principles pertaining to the phenomena of bird flight, a subject successively considered by a number of the ablest physicists and mathematicians in the annals of science without obtaining a satisfactory solution. While some have ventured tentative explanations of the soaring of birds and made fairly good guesses, so far as the author is aware, none have to this day pointed out the main principles and causes rendering this at first sight so surprising effect possible; hence no practical results have flown. The reasons for this must be sought mainly in the difficulty of founding conclusions in adequate premises, since the facts to be explained as to an extent conflicting, capable of being misunderstood and even in a measure questionable without a most painstaking and careful series of observations taken during fleeting moments of uncertainty both as regards atmospheric actions and responsive reactions of the birds. Also, it may be advanced as a reason that many of these eminent men, occupied with other work, gave the subject but a cursory attention, little dreaming of its surpassing practical and scientific worth. As to its importance for practical purposes, this, it is hoped, will be made sufficiently evident throughout these pages, and time will more surely sustain this point. But on the purely scientific side, its importance may be equally far-reaching in opening up suggestive channels for new thought, experiments and work serving to add to the knowledge of the physical universe.

As an abstract this work leaves much to be desired. This will be readily noted by the competent critic. It endeavors to cover the field broadly; to establish a working knowledge of fundamentals and indicate mechanical principles underlying flight and aerial reactions in such way as to open up a varied field for experimental work and academic treatment. More attention is paid to the one problem of how the atmosphere furnishes the driving power in bird flight than the equally, or in fact more important principles underlying sustentation. The accessory requirements of muscular power and its application, steering and equilibrium are likewise barely outlined, as is a multitudinous series of proofs of a direct and indirect nature the inclusion of which would extend the work more than desired. The writer intends to remedy in part these deficiencies as soon as opportunity presents and hopes the subject matter herein contained, short though it may come of producing absolute conviction, will evoke enough interest to lead to an invitation to do so.

Seattle, Wash., April, 1913.

* * * * *

2. In considering the mechanics of bird flight, four general problems are presented: (1) The fundamental principle of sustentation; (2) the nature

and principle of application of the driving power rendering sustentation possible; (3) equilibrium, and (4) steering.

Important subdivisions occur under each head; thus under (2), the problem more particularly selected for consideration herein, the nature of the driving power is of two kinds, viz., atmospheric and muscular, the principle of application being substantially the same for both. Of these, atmospheric energy is with a great number of birds the most important, furnishing in certain cases nigh on 100 per cent of the total power consumed. Of testimony from direct observation to prove this there is an abundance in literature. Many notable writers of unquestionable integrity and sane powers of observation could be quoted, but it is a matter which anyone interested may with little trouble verify for himself by observation in the open. Darwin in his journal (Voyage of the Beagle, p. 223), referring to the flight of condors, says, "Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima, I watched several for nearly half an hour without once taking off my eyes. They moved in large curves sweeping in circles, descending and ascending without once flapping. As they glided close over my head, I intently watched, from an oblique position, the outlines of the separate and terminal feathers of the wing; and if there had been the least vibratory movement these would have blended together, but they were seen distinct against the blue sky. * * * If the bird wished to descend, the wings for a moment collapsed; and then when again expanded with an altered inclination the momentum gained by the rapid descent seemed to urge the bird upward, with the even and steady movement of a paper kite. * * * It is truly wonderful and beautiful to see so great a bird, hour after hour, without apparent exertion, wheeling and gliding over mountain and river."

Had Darwin taken in account a few other facts pertaining to this phenomenon, it might have added to his perplexity to discover, for instance, that the air-speed of these birds and others of the soaring types, as well as their speed over the ground, is usually far greater than any velocity the air has in any direction; that thus this air not alone supports them gratuitously but also transports them to any destination at a more rapid rate than it flows. He migh have found also that the heavier the birds the less in proportion is the area of surface they spread, etc. The subject is replete with mechanical paradoxes. But these on resolution appear to violate no law of motion or conservation of energy. None taken singly that I can see present any greater difficulty of solution than such well-known fluid phenomena as shown in the steam injector, syphon, trompe, water ram, curving of baseball, ball-and-nozzle puzzle, balancing of rubber ball on a jet of water, etc.—all of which should yield to proper philosophical reasoning, even though some of them have not as yet been properly explained.

Facts from observation also tend to prove that the larger the species the more evident is its ability to dispense with muscular power and use atmospheric entirely. If nevertheless no very large animal has been evolved for flight, this is readily explained by natural causes, having regard to special fitness of things in mode of living. The greater the weight, the larger and more cumbersome in some ratio perforce must be the supporting surfaces to carry the weight and the slower and less dexterous the aerial evolutions possible. A happy mean is thus ordained in nature by the mode of living most convenient to the species; and large bulk of body can hardly have any advantage per se. Fossil remains to be sure have been found showing that flying creatures once existed on earth of a size quite twice as large as any now to be found, but they were evidently handicapped by their weight and large unwieldy surfaces in competition with smaller and more dexterous flying animals of their age, hence, and in connection with other contributory causes, became extinct. With the arrival of "man flight" such limitations largely disappear, as the means for flight form no part of his anatômical structure and it is less necessary that he should be able to perform "aerial gymnastics."

The increasing dependence on atmospheric driving power with increase of weight shown in the animal world furnishes a hopeful indication that this source of energy is the one destined to play a most prominent part in the future of aerial navigation; in fact, if artificial flight is to become a factor of any importance in human affairs, it is safe to say that it must be utilized and the delicate, expensive, limited and uncertain power plant relegated, as is muscular power in the animal kingdom, to the role of a convenient auxiliary except where unusual speed is a special object.

3. The purpose of this work being to indicate the essential principles of soaring flight and wherein lies the efficiency of the flight organs of birds, the question must naturally come up as to wherein they are differentiated from the artificial product of the day. Here and at the outset, however, I would say that, though holding no brief for the bird and wishing to be fair, a comparison reveals a frightful state of affairs unfavorable to the artificial product. It has been ascertained that the cool light of the firefly is about 95 per cent efficient, whereas our best artificial light shows about 2 per cent efficiency. Far greater is the chasm separating a bird wing and an aeroplane surface in mechanical efficiency; they appear to be related as positive to negative. Since I did not invent the bird, however, but have only undertaken to interpret its superior system in mechanical terms, no one need take exception to what the comparison discloses other than those who may feel themselves arraigned as awful blunderers in the practical art. They are few while those who have progress at heart are many.

It may be stated beforehand also that the main difference is found to lie in certain peculiar qualities characteristic of all natural wings, as distinguished from form and dimensions in relation to weight supported. And these qualities refer more particularly to a combination **in a system** of **elasticity** and **lightness.** With but slight and unimportant exceptions—and such show no system or proper appreciation of their importance—the incorporation of these qualities in aeroplane surfaces has not hitherto seriously engaged the attention of builders. Led to their course by numerous instances of breakage due to apparent material weakness, it is true, nevertheless, that their aim has been to obtain a maximum strength with a minimum weight of material, but in their primitive methods of construction this strength has, for incidental unavoidable causes, been associated with rigidity and the question of quality left out as of secondary concern, not recognizing that rigid, unadaptable surfaces are under the circumstances in which they operate a source of weakness just because they are rigid and are heavy because in combination with rigidity more material is necessary to provide a reasonable factor of safety. Thus, aero-surfaces, one may observe, are fixed in place to stay the same whether the aeroplane is in the air or in its shed. Of course no known material is absolutely rigid and unyielding, and so even wires and stays drawn tight by turnbuckles or other means have a certain amount of "give" or elasticity to them. Still, by far the greater number of accidents that have happened are traceable to no other cause than that these parts were unable to "give" enough, or avoid being overstrained, when subjected to sudden great stresses incident to conditions met with in the atmosphere, the inertia of the aeroplane as a whole preventing it from responding in the short time given to the sudden excessive pressures arising, with result of breakage or disturbance of equilibrium not possible of correction in the time given. Accidents are thus frequent in spite of the fact that in the best up-to-date engineering practice devoted to this art, wing structures (stays, uprights, beams, etc.) are given a margin of strength of three, and even more times, over and above what is required for resisting the stress due to the weight supported alone.

But the effect on the air, from a point of view of aerodynamics, is even more disasterous owing to the unyielding, unadaptable nature of such construction. In flight the rigid aero-surfaces, pushed or pulled along by a tornado-producing apparatus, dash through in a straight line and break up—bodily displace—tons of air every minute of action, vast quantities of energy being thus dissipated in causing useless and wasteful disturbances which with proper designing, in accordance with the perfection of bird wings, could be largely avoided. Most marked perhaps is this the case in violently disturbed air, as in stormy or windy weather; and the air is never truly calm. Aviators speak of it as "boiling," of finding it full of "holes," strewn with "rocks," "boulders," etc., and thus quaintly but truly describe causes for shocks, sudden drops and destructive vibrations which they experience in moving at great speed through an atmosphere in which masses of greater or less extent have a variety of relative motions.

Nature's flying machines behave differently in these circumstances! To a bird "boulders" and abrupt depressions, "holes," are nothing but gentle undulations on an ideal "road surface," over, or through, which its wings glide and accommodate themselves automatically to a fairly even reaction by virtue of their articulated structure, shape, lightness and manner in which held in position by elastic ligaments and tissue, pivoted on ball-and-socket joints. But what is more, and as will be shown, instead of being a hindrance and causing added effort, the "unevenness" of the air is a most welcome circumstance to birds, enabling them in fact to dispense, more or less and even altogether, with muscular power in sustaining and giving them direction in the air.

* * * * *

4. The method of attacking the problem must of necessity be largely inductive. The atmosphere "as it is" cannot be successfully reproduced within the confines of a laboratory; and if it could, experimental results so obtained, if intended to explain facts of bird flight, would still be of an indirect character and contain large elements of uncertainty. But, as will be shown, the facts to be explained may be rendered intelligible according to accepted standards by a more direct and certain path than through the results of more or less accidental happenings in a laboratory, by simply taking for granted that the atmosphere and the phenomena of bird flight taking place therein conform to known laws of matter and motion. The only difficulty in applying these laws consists in collating all the factors bearing on the problem and assigning to each its relative and proper value. This difficulty may be appreciated, but is still not of an insuperable kind. If I fail of complete success in the endeavor, leaving much to be added and rectified, I am nevertheless thoroughly convinced the method is correct and the only one that

can be productive of fruitful results in this field. If adopted and pursued further by those more fortunate and able than myself, the mechanics of bird flight will, I believe, soon fall in line, and take its place with analogous and more exact sciences; as, the mechanics of planetary motions, electricity, theory of sound, light, heat, etc.

An inductive-deductive analysis of bird flight may take a wide scope—as wide in fact as the world—embracing considerations pertaining to nearly all branches of science, if partly only in a negative sense. One may question: (1) **Physiology** (to give us an idea of the amount, character and metabolism of the food consumed by a selected species, and its organs for conversion of food elements into energy producing combinations, for inference of possible energy output); (2) **morphology, anatomy** and **engineering** (by skeleton structure, size of muscles, force of contraction, their arrangement and leverage, determining probable extensive and intensive capacity for mechanical work); (3) **natural history** (limited to mode of living and facts regarding sustained flight capacity); (4) **facts** of direct observation covering the mechanical aspect of flight (intuitive and by accurately determined data, as, air-speed, wing-beats per unit time, etc.); (5) **electricity** and **magnetism** (as to possibilities of atmospheric and terrestrial having anything to do with the sustentation, driving power and resistances in flight); (6) **meteorology** and allied sciences; (7) **dynamics,** in conjunction with structural characteristics, quality, form and dimensions of the flight organs, shape of body and its weight, physical properties and behavior of the atmosphere, conformable to facts and the laws of motion, including of course mathematical analysis.

No endeavor is made to cover this whole field, nor is it believed necessary since it is no longer necessary to prove that man-flight is possible. A survey of the whole, however, I may say, demonstrates with convincing certainty that bird flight is a form of animal locomotion in reality **as easy as it seems** and does not "transcend any power of analysis" as one authority would have it.

As the work as presented herewith is largely a preliminary affair, results rather than an extended analysis of the steps by which they are determined and proven are given, except in matters vital to the whole where sufficient proof is always presented to make the results acceptable to reason. And for such proof facts of observation (readily checked and in reality a form of experimental proof) and established physical principles are alone used. Though an endeavor is made to treat the subject in a popular, readable form, it is hoped that those who would go into a critical study of it are versed in mechanical science, have clear ideas concerning its main tenets and do not object to a little independent work in either proving or disproving propositions given but brief mention; but it is earnestly requested that the whole be read to the end before a critical survey is taken of the parts, as the subject is somewhat involved and often assertions properly made in one chapter receive their support and better elucidation in a succeeding. In the last resort, nothing will so far silence a dubious attitude as experimental proof, more convincing than that now presented under one's very nose on all sides, and such can consist in nothing less than an aeroplane soaring indefinitely with its occupant independent of any power plant whatsoever. If the time and means had been at my disposal, I would have made the endeavor many years ago to produce such proof; but such essentials have not fallen to my lot; hence, if I may vent a feeling of disgust, am forced to fall back on mere words where concrete performance would have an immensely more telling effect.

II. MECHANICS OF THE ATMOSPHERE

1. The first essential to an understanding of bird flight is a working knowledge of the physical properties of the atmosphere, including its behavior.

Air possesses in common with all matter—

a. Density, which conditions weight, inertia, momentum.

b. Elasticity, being compressible and expansible to unknown limits.

c. Viscosity, or an internal factor of resistance to shear and elastic stresses.

As a gas it possesses no measurable tenacity or adhesiveness outside of that caused by its compacted state due to the earth's gravitational action. Not being an absolutely perfect gas, its molecules are bound to an infinitessimal extent by residual affinity and its characteristics might be variable to a very small extent owing to difference in moisture content, unequal distribution of suspended particles and other impurities; but for our rather rough purposes we may well disregard such matters and consider it as a perfect gas devoid of cohesiveness, etc.

As to a, b and c, it is not intended herein to consider variations due to temperature differences, elevation above sea level, etc. To simplify matters, these factors are assumed constant and as occurs under average conditions near the surface. In a more complete work they would have to be included.

2. It is difficult to find anything tangible with which to contrast certain attributes of the atmosphere, so, to facilitate explanation in certain places, recourse is had to imaginary atmospheres; that is, air differently constituted than the real. Those to be referred to are three in number:

(a) An "ideal" atmosphere—By hypothesis **inert** and as the real, but deprived of viscosity or ability to cause shearing, frictional and restitutional resistance stresses.

(b) A "neutral" atmosphere—Also largely fictitious, in which we suppose it to have no internal movements except basic (molecular, etc.); i. e., an air that is ~~either~~ in stable equilibrium, quiescent, or flowing as a steady horizontal stream without deviations. A condition of air, it may be stated, sought for in aerodynamical laboratories but never truly produced by artificial means.

(c) An "ideal-neutral" atmosphere—Combining the characteristics of the ~~former~~. [illegible]

The atmosphere "as it is"—the real atmosphere—is the only kind that counts, however. A mere definition will not suffice to make its intricacies understood, so the purpose of this chapter is mainly to describe the proximate true behavior of the atmosphere, and mechanics pertaining thereto, and thus provide indispensable premises for explaining the phenomena of bird flight and what they may portend of value to the present budding art.

3. **Atmospheric Movements.** The atmosphere in which we are immersed and breathe has many peculiarities and is swayed by many influences into an erratic behavior. Just because of its transparency and ~~as~~ it does not otherwise obtrude itself very forcibly on sense perceptions, this is accepted in everyday life with little though as matter-of-fact. Even those who would use it as a "roadway leading everywhere" thus slight and neglect to take in account its many vagaries; so no wonder soaring flight, for one thing, is not understood.

The atmosphere, as is well-known, is never in a state of complete rest; it always presents itself in a more or less agitated condition, whether with reference to the ground or in respect to itself, i. e., as a mass of moving particles "within itself." The primary causes productive of these movements are little understood but undoubtedly in great part due to actions and reactions between the earth and the sun. Discounting the action of the moon in causing insignificant aerial tides and seismic effects of occasional influences, temperature differences and changes are generally accounted the main causes for the unstable equilibrium. This may be allowed so far as certain vertical movements are concerned, but does not account for the extensive horizontal movements observed. Mechanically, the action of heat on air is to expand it, thereby producing vertical displacements. Only as a comparatively insignificant attendant component, and secondarily thereto, can horizontal movements be induced thereby. More tolerable is the theory that magnetic or (?) electrical forces (originating in the latent stores of energy within the earth or by an obscure method of induction from that immense reservoir of energy, the sun) produce these movements, air being susceptible to magnetic influence and always more or less electrically charged. High and low pressure areas; the intermittent, spasmodic flowing of the air horizontally; proportions obtaining between vertical and horizontal extensions of such air; the rotary motions of all considerable winds, etc.—all denote electro-magnetic origin, or as due to causes other than temperature differences. During periods of maxima sun spots terrestrial magnetism is sympathetically affected, we have magnetic storms. A few days after one of these is noted the newspapers invariably, as I have casually observed, report great havoc wrought by destructive wind storms. It takes time to set immense masses of air in violent motion or for the forces producing the movements to become so adjusted as to affect the air.

These aerial movements, whatever their origin, are greatly modified by a number of factors, as, differences in electrical potential, evaporation and condensation of water, and surface conditions of the earth. It is possible to classify them roughly by considering the causes contributing to their origin in connection with the modifying factors, but of the latter, surface conditions alone will here be given attention, as others are of little or no importance to the present issue.

In these movements two grand groups are clearly to be distinguished as mechanically different, viz.: (a) fluid movements and (b) elastic-solid movements.

All aerial movements, however, are relative and internal; that is, they are relative to the surface of the earth and other parts of the atmosphere, and they are internal because the grand mass of the earth's atmosphere is fairly stable. Their only distinguishing traits (except as indicated above) are quantitative, directional and velocity differences. We have movements of great dimensions and small to extremes in every conceivable direction and of varying velocities. In reference to direction the movements occur in space of three dimensions, and so are horizontal and vertical in more or less component combination. As will be more fully understood by later developments, the movements having a vertical component are our main concern and only as incidental to their determination are those in the horizontal plane considered.

(a) **Fluid Movements.** Under this head come all sensible movements involving relative displacements of unit air masses—bodily detachment of air masses from their surrounding, though contiguously related to all the air.

Any wind furnishes an example of a "grand movement" of this nature. But within such a "grand movement" a great variety of "minor movements" takes place concurrently. As one knows, the air never flows in a steady stream in windy weather; its progress is by "leaps and bounds," or so-called "gushes," of varying magnitude and velocity. The squally nature of winds blowing over the seas is familiar to all who have sailed a boat. And though the "grand movement" itself may hold a fairly steady course, the direction of its constituent parts continually change or deviate. We thus observe masses, often of hundreds of tons in magnitude, hurled through space, overtaking and striking other masses of slower speed, "mushrooming" and imparting their momenta to such other masses, to be themselves, in turn, struck by succeeding masses and pushed forward, sideways, up or down. The progress of the component masses of a wind movement is analogous to that of billiard balls striking each other, and like these in transmitting their momenta the masses struck are deflected in various directions, only not so much according to angles of impact as to the paths of least resistance presented which always lie in both vertical and horizontal planes. The behavior of a wind vane gives one an idea of how air masses are thus violently deviated in the horizontal plane; but in the vertical plane the same holds true, and even more so, due mainly to the greater irregularity of the earth's surface in this plane, according to which the stream lines of the moving air roughly conform. The air thus in a sense bounds and rebounds in the progress over the surface, as though it were composed of very elastic and light rubber balls, and these deviations of "ground air" affect strata high above, though, as we shall see, not in a strictly fluid way. As the wind causes waves on the surface of the sea so is it in turn affected by these, being deflected upward and forced down according to the wave configurations.

Incident to the frequent heaping up of relatively dense masses in one place, with corresponding attenuation in other, in horizontal winds, it follows that aerial movements occur which partake of the characteristics of the wave forms of the sea. Through the action of gravitation, a relatively dense mass of air forced up in one place must seek its level or balance with other masses of less density occupying a lower position. Free (unbalanced) energy in the positional form is therewith introduced in the atmosphere "within itself" and oscillating, transverse-longitudinal, slow-moving upheavals and declines arise, identical in main principle with the ocean waves. The faster moving superior layers would tend to shear off and displace the crests of such waves, and so their general direction is as the wind blows. Perturbed as they of necessity must be by the interlaced buffetings of the onrushing air in which they are inscribed, and on account of absence of any well-defined surface for such wave action, it is hardly strange that we do not become directly aware of them, unless, indeed, and as may be strongly suspected, the fluctuating velocity of horizontal-flowing air is their direct evidence. Alternate translation of atmospheric energy into positional and kinetic forms would, to my mind, be perceived by a person on the ground as a pulsating flow of the air; though it should not be considered the only or even the main cause contributing to effect such flow. Both theory and observation of the behavior of birds in flight indicate the presence of such wave action in the air; though it might be disputed on the ground that dense masses hurled up amongst less dense would have a tendency to establish their equilibrium by expansion to even density with the surrounding. Now, undoubtedly such expansion takes place, but it must be considered in proportion slow as the masses concerned are large, so that with greater masses plenty of time will elapse for the gravitational reaction to take place and set up oscillations of this character which require notice in our reference. These waves once set agoing would be augmented and kept going by the action of faster moving air above, on the same principle as the ocean waves are sustained; and the faster the wind, the greater their size and violence.

The fact that air at a high level travels faster than at a lower moreover suggests—and of this I have seen some indications in snow storms—that the progress of winds, at least near the ground, is rolling as well as sliding, with axis of rotation at right angles to the general direction of flow. This might be explained as due to the retardation suffered by the lowest layers in contact with ground and incident gaseous shear retarding adjoining and superior laminae in succession, and to the separation of the onward moving air into parts of differential velocity, which would tend to promote the rolling. Air at one instant in contact with the ground thus soon thereafter may be found high in position, and vice versa.

On comparatively calm days, too, considerable up and down movements of air of an irregular nature take place, owing to unequal temperatures and densities of air masses heated by contact with the ground. Boiling water suggests the action quite vividly though one may often observe it more directly by the refraction of light. The uneven ground heated by the incident rays from the sun, it is reasonable to assume, gives rise to a far greater irregularity in the up and down movements of air masses heated therefrom than is the case with water heated in a smooth-bottomed kettle. As the numerous small steam bubbles forming at the bottom of a kettle of boiling water converge and form larger units which break through superior layers to the top, so with air in this case as observation shows. On account of the inertia of superior strata of the atmosphere, the first, or strongest column of heated and expanded air over a given area succeeding in breaking through is followed by others through the path of lessened resistance thus provided; the breech is gradually widened, and soon, owing to the pressure of the heavier superincumbent air all around, there is a general convergence of the lighter, hot ground air from a considerable area toward this point, where it rushes upward with considerable velocity. The grand column of rising air thus formed spreads out when reaching a stratum of specific gravity equal to its own, and the combined result of a great number of such columns may largely account for observed temperature differences among lower atmospheric strata, though, of course, as air expands its heat per unit volume diminishes in proportion. Still, as this cooling by expansion is often compensated for by transfer of the latent heat of the air's moisture content to the air as such gaseous water condenses to fluid drops or visible vapor, it is not altogether unlikely that herein may be found the explanation of the formation of certain low-lying isothermal layers of temporary character. Be this as it may, it is certain, considering the physical manner in which the air is elevated in temperature, expanded under stress of the over-lying air at the ground and subsequently affected, that within the rising grand columns the smaller units whereof they are composed have different vertical velocities. In other words, a considerable "unevenness" of the air within the rising masses may be inferred.

These directly initiated vertical movements, or convection currents, connected with pre-existing winds buffeted in all directions by surface obstacles, makes for an indescribable turbulency of the lower part of the aerial ocean. Kite experiments and watching smoke from chimneys, etc., make this very plain when carried out over some period of time and with sufficient variations.

In all movements of a fluid nature the principle holds true that "what goes up must come down," so on an average the downward trends of air equal the upward over the whole earth's surface.

While insistence is made that air tends to deviate in vertical directions in windy weather, it is of course obvious that such air for great lengths of space and time has a "neutral" flow. It deviates only when a ~~resistance or~~ force causes it to deviate.

(b) **Elastic-Solid Movements.** In this group is comprehended a number of movements secondary to, and accompanying all fluid effects, obeying the laws of sound. They are by far the most important in our survey.

It may be evident at once, considering that we are dealing with a gas of almost perfect elasticity, that as the separately moving masses described give rise to collisions between themselves and objects in their paths, such collisions in turn, due to the inertia of the air, cause momentary changes in density of the masses in vicinity of impact; that thus elastic (longitudinal) waves, irregular in magnitude and amplitude and generally of a lower pitch than audible sound waves, arise and spread in all directions at sound velocity. The rattling of windows and shaking of buildings on windy days are suggestive of the prevalence of these deep-noted pulses in the aerial ocean, which one may readily observe are dissociated from, and acting independently of fluid-moving masses and their more direct impacts.

The readiest, if not the surest and best way of gaining an insight into this phase of atmospheric conditions is the inductive; proceeding from the known to the unknown by logical steps. Results so obtained should of course, if true, be referable back by deductive processes and might be capable of more direct verification by experimental means (as, using sensitive, self-recording pressure gauges and other instruments in connection with kites, etc.). However, the procedure may be varied and include a great number of certain premises, with the postulate of conservation of energy serving as the anchor around which to swing the discussion. With such anchorage we cannot go far astray.

Now, much has been written on facts pertaining to the circulation and movements of the atmosphere, and in a general way the **immediate** causes of its movements are understood. It is presumed that the sun induces the movements by creating differences of potential in various localities, and acts as such with a power amounting to a staggering total expressible only in countless millions of horsepower. Measurements and estimates are powerless to give exact figures for this powerful drive. The question is, what are the resistances opposing this action, and how are the movements brought to a standstill, as we know they are in spite of the constant increment to motion received from the sun or other sources? It is clear that the resistances must balance the driving power on the whole and average; consequently also be equally tremendeous. I have come across practically nothing on this point and will attempt to show in the briefest possible manner wherein they mainly consist, as it proves the existence of a form of energy that plays an important part in bird flight, as well helping to clear up and supplement facts pertaining to atmospheric mechanics and behavior in general.

As an **a priori** proposition, in line with the conservation theory, it must be assumed that atmospheric "grand movements" are somehow changed into **basic movements** (molecular, atomic, electronic), or into a form to permit their energy to leave the earth system via the luminiferous ether whence the energy came. And it is a question of tracing the succession to this end. For, since the ether is space-related (does not permit of instantaneous translation of radiant energy) it is given that all energy received by the earth from without must pass through its atmosphere, coming and going; and apart from an insignificant amount of the total that becomes "fixed" in some form or another, the efflux must in the long run equal the influx. Otherwise, think of consequences! The atmosphere is said to form a protective blanket around the earth, of a selective type, so that while it permits the entrance of radiant energy with relatively little absorption it detains a relatively greater portion of the reflected rays by greater resistance. This may be because the solid and liquid surfaces of the earth and vapor and solid particles suspended in the atmosphere change the wave lengths from an harmonic to an, for a gas, inharmonic phase. Yet, as the heat and other forms of energy received in spite of this departs, it is obvious that through devious paths the proper wave lengths are again attained to permit their departure. While this is not an inquiry into this question itself, we have to follow for a little way the energy transformations, and it is well to have the main route identified, even in a tentative way. We strike the road where some of the cosmic energy received has the kinetic form in aerial movements, and we must follow it until the point where this energy has assumed a form to affect the ether, permitting return to space. This brings us to the question of **What stops the winds?** No more than a hurried sketch is attempted.

The most obvious causes for the retardation and stoppage of wind movements are: (1) Opposing aerial movements; (2) friction between the air and the earth's surface; (3) demonstrable effects, or work done on water and land; (4) surface obstacles of all kinds, and (5) internal frictional resistances of the air. Taking these in turn—

(1) As to opposing winds and inert resistances in the atmosphere, to this no retarding action in itself, of a permanent, absolute nature can be properly assigned. It explains perhaps certain temporary calms and to a great extent changes in direction of winds, but that must be counted all. Colliding air transfers its kinetic energy into a potential form which is of necessity temporary and produces, apart from effects to be noted later, as much movement as produced it. As to inertia opposition, it means but retardation of some air and acceleration of other, so does not count in the broad view taken.

(2) **Friction Between Air and Solid and Liquid Surfaces.** One would not be backward in assigning a great value to this factor, and to sustain the contention there is the demonstrable fact that the velocities of winds rise, as a rule, at a steep gradient above the surface of the earth. A wind blowing 20 m. p. h. near the ground generally has a velocity twice as great or more a mile above. Good reasons could be advanced for believing the contrary—but for facts. Difference in densities might suggest that the lighter upper air would be more readily set in motion and attain its speed by the action of a given force than heavier at low level, the mathematical rule being that the velocity imparted by the action of a given force in unit time varies inversely as the mass affected: but, on the other hand, the constant

tangential stresses between layers of different velocity would tend to equalize this in comparatively short order, so will not explain much. There is of course, too, the rolling tendency of the air to account, in part, for the differential speed; but this may be safely ignored as just so much additional testimony to the great difficulty air has in flowing over the uneven surface, whence this way is necessarily adopted because it offers less resistance than sliding alone.

It must be admitted that velocity differences of high and low strata are conclusive on the point that the earth's surface is the main cause in retarding aerial movements. And this leads, in the first place, to the question, what is understood by the earth's frictional opposition. Should it be considered broadly as embracing all kinds of retarding actions, or narrowed down to the tangential resistance between the moving air and solid and liquid **even** surfaces? For reasons that will be obvious we must adopt the latter view and consider resistances offered by projections and irregularities of surface contour apart. A sharp line is hard to draw, however; for what is an "even" surface? and what is friction in this case? If the kinetic theory of gasses holds true—and so far it has never failed in consistency—there could not likely be such thing as friction between an absolutely even, or "ideal surface" and the air in absence of adhesive and cohesive properties in the air. By an "ideal surface" I mean one without even molecular irregularities and interstices to afford a "grip" for the contact film of onflowing air. But an "ideal surface" is a material impossibility, so friction is a fact to be reckoned with. Even the most highly polished surfaces produced probably have irregularities of microscopic dimensions, let alone the question of molecular. But strictly speaking only the resistances offered by irregularities of molecular dimensions (not protruding aggregates) should be termed friction, and those due to greater irregularities, grading from microscopic to mountanous proportions, otherwise accounted for. So if a line is to be drawn, **here is where** it must be drawn.

On ordinary "even" surfaces experiments have been conducted by various men of science, notably Prof. Zahm, to determine the co-efficient of aerial friction. They have resulted in showing aerial skin friction about the same as for water in proportion as the latter is more dense, or roughly as 1 to 800. We know at least in an intuitive fashion what frictional resistance water opposes to a smooth, moving surface, and dividing this by 800 gives an idea of what air friction proper amounts to. Friction being due to irregularities of surface would likely cause rolling of the contact stratum of air, proportional in extent to the irregularities, and might be variable owing to moisture content of the air and differences in temperature of air and friction surface. However that be, to the frictional resistance offered by obstructions of molecular dimensions to flow of air, be the surface solid or liquid, we must assign an insignificant and wholly negligible value as compared to the immense forces at play. The problem is to account for the wholesale "lost motion" in terms of work done by the wind and not productive of further similar air movements, and so we may proceed to—

(3) **Demonstrable Effects,** or work done on water and land of a more or less "fixed" character.

(a) **Formation of Waves on Water.** Aerial skin friction has hardly any influence in causing this. I doubt whether a "neutral" flow of air could of itself produce waves on an absolutely level, smooth surface of water. The surface tension of the water would prevent the formation. There is needed so to say a catalyzer in the form of the smallest ripple to start with. This given, the air obtains something to act on, and the process is rapid toward the formation of the largest waves. This is visible work done by the wind and it is dampened accordingly in both starting and keeping the waves going against viscosity resistances of the water. That this amounts to transfer of energy in huge proportions is obvious. Part of this energy, however, is immediately returned in causing synchronous up and down movements in the air and considerably more may in other ways be productive of renewed potentials and movements in the air. It would be largely a matter of a broad guess to say how much this abstraction of energy amounts to in proportion to the total losses of the atmospheric circulation. It is likely, though, in view of what follows, that it is less than one-fourth of the total.

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(b) **Effects on Land.** It is a readily ascertained fact that wind velocities over the oceans are on an average far greater than over land, spite of the more active increments to such motion caused by solar action on the continents. Without entering into the complex causes tending to the distribution of the potentials, the influence of mountain ranges at low levels, etc., there is herein indicated that the resistances to flow over land are greater than over water. And what are the visible proofs of **work** done by the countless cubic miles, or millions of tons, of air sliding and rolling over the lands? We observe swaying of tree tops, branches, bushes, grass, etc.; rustling of leaves, some dust clouds here and there, occasionally some few million tons of snow moved into heaps, etc. But, within reason, what does this amount to even as compared to the work done on the oceans in maintaining its waves and turbulence? It is obviously quite negligible and by no means "fixed" in the proper sense. A tree caused to swing has work done upon it by the air, but owing to its elasticity it reacts and does practically as much work on the air in return. Little is "kept."

There should under this general head also be reckoned the energy losses suffered by winds in imparting momentum to water vapor elevated by the action of heat, and the momentum abstracted from them under certain conditions when the vapor condenses and drops to the ground. The total of this work, though proportionally not great, is not quite negligible. The translation of the latent heat of vapor to the air, as it condenses, together with electrical storms often associated with rainfall may, however, render such transactions more positive than negative of wind movements.

(4) **Obstacles.** These grade in size from mountainous to microscopic and are of every imaginable kinds, liquid and solid. A wind of any magnitude flows over and against billows, hills, ridges, cliffs, valleys, small mountain ranges, between and over houses, trees, etc., and follows undulations of the surface in a general way; but the principle of least resistance comes into play and it skips to a great extent from high point to high point. This skipping tendency no doubt accounts largely for the observed velocity difference between high and low strata, by the difficulty ground air (being jammed down by the weight of higher air and its inert resistance to vertical displacement) has in "climbing" hills and other obstacles; but it depends on locality and in no manner can it account for the wholesale arrest of motion taking place throughout the atmosphere. For if ground air is forced to the top of a ridge at a loss of momentum, it regains practically as much in "tumbling"

down on the other side, and properly speaking there is no motion "lost" in the long run from this cause over the earth's surface.

The action of obstacles in causing a complex turbulency of flowing air has been briefly described under head of "Fluid Movements;" but as to their abstracting any energy from the moving air, this they are incapable of unless the colliding air elevates their temperature, or deforms or shifts them in position with attendant frictional opposition. The reader will draw his own conclusion on this point, and also in regard to whether such transmitted energy may not find its way back into the atmosphere and produce renewed agitation.

By elimination, and after weighing roughly all possible factors of the problem, I see no other way to account for the wholesale retardation of the winds than by concluding that, in virtue of the action of obstacles and causes producing turbulency, the air is forced to do work upon itself; that thereby its internal resistance factors are brought into play so as to increase its entropy at expense of high-grade energy. For, were the atmosphere "ideal," as defined, aerial movements once set agoing would continue forever, and with the accelerating forces continuing their action, such movements would be gradually augmented up to the point where critical velocities were attained, when such atmosphere would say good-bye forever and depart into space, followed in short order by the ocean waters if not possessed of a countervalent internal resistance factor. So, coming to the internal resistances we enter a more promising field for discovery of what is wanted.

(5) **Internal Frictional Resistances of the Air.** These are (a) shear-resistance in fluid movements and (b) restitution-resistance in elastic-solid movements; both essentially the same and as a rule called **viscosity.** The latter is a convenient term and will be used herein, though it seems misleading when applied to a substance practically devoid of adhesive and cohesive properties, whence not in this case a form of absorptive resistance due to sundering of molecular bonds.

(a) **Shear-Resistance.** This comes into play in all cases where contiguous air masses have relative motions, at planes of contact, and it due to the motions of the molecules normal to, and across the shearing planes and consequent inertia opposition. We can prove its existence by its effects, and these are shown in that all fluid movements have a tendency to enlargement by dragging with them contiguous air in their onrush. It is, however, of no simple description such as ordinarily associated with the notion of shear, This is because it occurs in an exceedingly elastic fluid whose molecules have practically no other bond than that due to the earth's attraction and which (molecules) except for their inertia are free to move in any direction when acted upon by a force, no matter how small. They therefore individually and in aggregates take the path which offers least resistance when acted upon by a force, and the proper factors whose resultant determine this path is their own inertia, direction, magnitude and intensity of the force acting and a complex series of disturbing influences caused by elastic and fluid movements within the moving units themselves and contiguous air. Owing to these circumstances, there never was, or can be, a plain shear between layers of moving air, in which we should imagine but one plane of definite thickness as affected. One may see this when blowing smoke in the air. Vortices are formed and the shearing planes are generally of a rotational kind, indicating plainly that everything conforms to that course which offers least resistance. Between two superposed contrary winds, such as are frequent in the upper atmosphere, one may thus safely infer that there exists neutral zones in which all kinds of eddying and rotational movements take place; and instead of a single shearing plane it comes to pass that there are billions involved in every stress of this kind and of the most complex configurations. These stresses are in their nature frictional and, according to the kinetic theory of gases, can hardly be due to anything else than inertia opposition of the molecules coming in collision along the innumerable shearing planes. This being the case, in proportion as these collisions add an increment to the velocities or range of the molecules concerned, is energy degraded. This is not saying that the transformation is quickly effected, or on an intensive scale, in any local action of this kind; experience and theory would contradict such supposition by showing, that, though any shear-stress is a compound one of molecular adjustments along numerous planes, only an exceedingly thin film is, figuratively speaking, "peeled off" during the stress and deprived of high-grade energy in the way indicated. But in the aggregate and long run throughout the atmosphere, the degradation thus caused must be enormous and probably accounts for as much as one half of the total retardation of winds as they are churned up at the surface and stressed upward (in a geometically diminishing ratio) along the laminae-planes of the air as far as it extends. Yet the effectiveness of this factor depends to the greatest extent upon another, though not quite as formidable form of resistance, viz:

(b) **Restitution-resistance.** Which may be defined as that which prevents the noises of yesterday from being heard today, and described as substantially akin to shear-resistance, except that it occurs at right angles to plane of action in elastic stresses, owing to the rapid molecular motions normal to the direction of the mass displacements involved, and is effective for transforming energy from mass movements to the basic forms only during the time the molecules are crowded closer upon each other or separated more in compression and expansion stresses, or when their relative inert states are disturbed in that way. Due to this resistance, no complete energy restitution is possible in mass displacements involving alternate kinetic and potential forms; there is a small tribute exacted by the molecules, so to say, which they keep for their service in passing the waves onward. That this tribute, or coefficient, is very small compared to the total energy involved in such transactions, is sufficiently indicated in that sound waves—a continuous alternation of kinetic and potential effects—travel for many miles before they are entirely dampened and vanish; although the fact must not here be overlooked that these waves are diffused in space according to the law of inverse squares and that, too, there may be other dampening agencies active than the aerial viscosity co-efficient alone to effect their annulment. The diffusion would in itself account for their disappearance in an audible form, but not their dampening to nil which facts and considerations of ultimates require. And as to other agencies such as are occasioned by wave impacts with solids and liquids, these involve the phenomena of reflection and refraction, or further splitting up and diffusion; but diffusion, it is well to remark, is not dampening or what that term implies.

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Of course this abstraction of energy from a wave train has nothing to do with the (adiabatic) constancy of its velocity. The energy of a sound wave is related entirely to the internal mass displacements (laminae movements) taking place incident to, but yet in a mechanical sense wholly unrelated to the velocity of propagation proper. Only that which alters the relation obtaining between the modulus of elasticity and the density of a substance can affect the velocity of propagation of elastic waves therein. By no way of consistent reasoning can it be held that the viscosity co-efficient touches this relation in a variable way, if at all. This co-efficient, whatever it may amount to in a quantitative expression, operates only to reduce the amplitude of an elastic impulse—its loudness if in conjunction with many in the form of a train of sufficient frequency—nothing else. Were it otherwise, another result would be inevitable, viz., the velocity of sound would diminish directly as the square of the distance from source of origin due to diffusion alone, something we are well aware runs counter to experience. Sound waves it is therefore safe to assert are absorbed in their travel by resistances that translate their energy into heat. And undoubtedly this absorption is the more rapid as the amplitude of the waves, due to diffusion, gradually diminishes to the average range of the random motions of the air molecules, so that when the point of coincidence occurs the annulment of the wave train is practically instantaneous.

This theory to account for the dampening of longitudinal wave trains may not be new, nor wholly true; but without further discussion, this much is certain: whenever atmospheric energy is translated into elastic vibratory pulses it departs with these from the vicinity of origin and is diffused at the speed of sound to unknown limits.

In this light it is interesting to note what happens when a wind sweeps over the surface of the earth. Obstacles of all kinds are encountered to bar an even flow—houses, trees, bushes, ridges, cliffs, valleys, small mountains, ocean waves, etc. These break up its lower portion into an indescribable variety of minor fluid movements, deflect them in all directions and **cause conflict.** In the turmoil and re-adjustment there arise an infinite number of impractual stresses or strains—an alternation of kinetic and potential effects—accompanied by a diffusion of wave trains and incident departure of energy. Thus, indirectly the whole atmosphere takes part in tapping the energy of any grand internal movement and retarding its progress. That this constant degradation of energy is enormous is evident. Due to this cause, coupled with what was said under (a) above, the wind moves with "leaden feet" and drags along the ground, with incident shearing stresses throughout its huge body, to a destination it is eagerly impelled to reach but never approaches with anything like the amount of energy that drove it.

Here this course must end. We have found with some approximation to physical reality what stops the wind and shown how its contained high-grade energy is returned to a more basic form. To follow it further and speculate on the question whether it is now in shape to leave the earth system or has to undergo further transformations in the endless cycle, would be a digression not warranted by the scope of this work. Only it may be remarked that herein is probably indicated one of the main routes along which energy coming from without must depart, and it shows the enormous energy the atmosphere is charged with and must dispose of. From recent data it has been estimated that the radiant heat energy received amounts to the equivalent of some 7000 horse-power per acre of the earth's disc exposed to the sun's rays. Electro-magnetic and other inductive effects may add immensely to this amount, though of course the greater portion of the energy received is reflected back into space without detention by the atmosphere. Wonder then that in this ocean of energy and motion we should find that which impels the graceful soaring bird to any point of the compass and to dizzy heights!

It will occur to anyone who would attempt to follow one of these irregular elastic pulses, arising, as stated, at the surface, and apply the laws of sound to the case, that no matter what its original direction, it must sooner or later have a general direction away from the surface; since the earth is round and presents all kinds of inclined planes for reflection of any part of a wave coming in contact with its surface. Well it is so, for if such pulses had a tendency to hug the surface, buildings and many other things might have to be differently designed to withstand the "pranks" they would play when by coincidence a great number of the more powerful ones should arrive at the same point at the same time. As it is, they, like ordinary sound waves, go a good distance along the surface, but with a thin edge that is sadly crippled, split and reflected in its progress. Balloonists, as a noteworthy fact, often dwell upon the "acoustic transparency" of the air in the vertical direction, hearing sounds from the surface distinctly, which by their distance they would not think could reach them. But even were the earth as smooth as a billiard ball the simplest considerations of geometry would show that by far the greater portion of the force of sound waves originating at the ground must be directed vertically. If a rocket is exploded in the air the sound of the explosion, and indeed the greater part of its energy, travels as a gradually enlarging bubble until its lower part strikes the earth and is reflected. If the explosion occurs at the ground the diffusion takes place as a double hemisphere, one the directly ascending and spreading and the other the reflected, that is, both travel in a divergent direction upward. Only the lower edges of these expanding hemispheres can touch the ground and this portion of the whole must be considered negligible.

According to this, the surface of our globe over which a wind sweeps constantly "radiates" elastic impulses outward. This "radiation" we shall see means energy in a form useful to the conservation of a system receptive to its action—as the soaring bird spreading its elastic surfaces in a way so as to intercept and dampen the impinging trains.

The energy content of each separate impulse, which is determined by its amplitude and proportional to the square of this dimensional factor, diminishes as it recedes from point of origin according to two things, viz., (1) diffusion and (2) restitutional resistance. The latter may be counted quite negligible for short distances, but the former is great. How great is the question, and it is indeterminate. That the diffusion of the energy of sound does not follow the law of inverse squares is evident, though the sound itself is diffused according to this rule. No one in calling to another person far away would think of turning his back to him. By the simplest considerations of daily experience we are led to believe that the energy of sound—its loudness—follows a slightly different geometrical rule and goes more forcibly in direction as projected or reflected than in any other.

But more so when considering the bearing of the principle of least resistance on the problem, in connection with the fact that air decreases in density in a geometrical ratio upward, it becomes evident that not alone the solid ground but the air itself tends to deflect and converge elastic waves with more force upward than in any other—that is, in direction from greater to less density—in a manner similar as a prism alters the direction of light rays, or, better, as a parabolic mirror by incidence of reflection causes divergent rays to take a parallel course. Only whereas in these analogous cases the change in direction is effected with angular abruptness, here we must picture it as a very gradual or curved one and as a process by which the constant tendency of the waves to divergence is counteracted by a factor tending as constantly to converge and maintain them in a parallel direction. This is not saying that these waves would travel faster upward than in other directions, but that their amplitude, or energy content, would be better conserved and tend to less diffusion along this line of decreasing density than in any other. The waves are free to diffuse equally in all directions according to the law of inverse squares but cannot do so when a factor enters prohibiting their following this tendency. Compare in this reference Sections 5 and 6, Chapter IV, especially on elastic impact relations between small mass and large, wherein may be found basic rules for reasoning more rigorously into the particulars of this phenomenon of motion.

For these reasons, and because of the immense number of elastic pulses radiated in an interlaced form from miles of square surface, the average energy of the radiation per unit area of horizontal air surface may be counted nearly as inversely proportional to the distance (height) of such surface from the earth's surface, as diminished only by the viscosity co-efficient. It would of course at the same time be directly proportional to the square of the velocity of the winds causing the radiation.

Now if the absorption theory previously advanced is correct—viz., that the viscosity co-efficient increases as the amplitude of elastic waves in air due to diffusion diminishes, becoming precipituous when synchronizing with molecular ranges or amplitudes—it becomes evident that sound waves can go so far and no further, depending upon initial amplitude to say where the threshold for their instantaneous exhaustion shall lie. And then, given that the greater number of the waves arising at the ground have approximately the same initial amplitude, that they obey the principle of least resistance in their travel, and considering that the molecular ranges increase with attenuation of the air, it would follow that there should exist in the higher reaches of the atmosphere a stratum of greater relative temperature than adjoining, to-wit, where the threshold named lies. This has been found to be so. Exploration conducted by aerologists by means of sounding balloons has established the existence of what is referred to as an isothermal layer quite uniformly enveloping the earth at a height of about 8 miles from its surface. This isothermal layer thus would have relation to the turbulency of the air at the bottom of the atmospheric ocean as a reflection of some of the energy abstracted from the winds in retarding their progress. This is merely mentioned as it seems to lend additional proof both to the absorption theory given and the quite constant progression upward of innumerable elastic waves in the air.

Trees are the most effective dampening agents that moving air masses have to contend with. Who has not noticed how long stretches of unbroken plain lighten the "feet" of the wind? Precisely in this may be found the main reason for the fluctuating flow of winds—their erratic bursts of speed. Not that such obstacles themselves directly cause great resistance, but because they induce conflicts between air masses that persist as elastic wandering movements for a long time until degraded as described. This might suggest that the fury of winds sweeping over our continents could be abated by concerted action of the inhabitants, extending over a half century or so, and probably at many direct and indirect economic benefits as well, by interspercing the landscape in a systematic way with alternate wooded and smooth sections; orchards, hedges, valuable timber, tilled ground, etc. There would thus be effected a more rasp-like surface than obtains in many places, against which the moving masses would be continually broken up, thrown in conflict, and caused to dissipate their energy. When civilization reaches a higher plane, some action to this end may be taken, especially as it would at the same time charge the atmosphere more evenly with a useful form of energy and improve the "aerial highways" so as to make them more efficient for travel. This might seem visionary, since only a very small portion of the earth's surface would be susceptible of such improvements; but even so it would count. The "aerial highways" will be much used 50 or a 100 years from now, to go no further!

Before quitting the subject under this sub-head, one other matter of immense importance should be noted. Namely, were we to follow the stream-lines of a wind movement from the ground upward to great heights, we should, as evident, find them indescribably broken and irregular near the ground, but the higher we went the straighter and more "solid" they would become, with deviations conforming **easily** to the general surface contour. Thus, a wind skimming over a number of hills or surface undulations would form a series of deviations within itself; that is, its stream lines would deviate up and down according to the ground contour, with due obedience to the law of least resistance, so that the lines would be "easy." But perhaps even more so, owing to the elasticity of the air, these deviations would be the less abrupt and more in line with the general direction of flow the higher they were viewed until at great altitudes they would practically disappear. Such deviations are caused no matter whether a mountain, house, or a clump of bushes on a level plain interpose to interrupt an even flow, and of course their magnitude, and we may add amplitude, are dependent on these original causes. Moreover they may be classified as temporary and constant: the latter due to constant causes (as a house or ridge), though they are constant only as related to space, not as concerns the air as it flows and is successively affected; the former due to fluctuations in the wind velocity, its transverse wave action, collisions and deflections, causing potential strains likewise extending is a sensible way to great heights and causing temporary "bumps" on the stream-lines of air which in other respects may flow more or less horizontally and as though solid. These deviations and "bumps" must be distinguished from those of a more vibratory kind, as the low-pitched sound pulses aforementioned, though they are at bottom identical and only to be differentiated by extensiveness and amplitude.

To go to further detail, surface irregularities cause extreme turbulency and conflicting fluid movements at or near the bottom of the aerial ocean, but said fluid movements are incapable of projecting themselves very far into the surrounding air in a fluid way. The inertia and elasticity of contiguous and remoter air prevent such projection. Any projected mass (not sustained by a constant driving force) thus—and as observed—"flares out" and issues into elastic strains by reaction of the surrounding air to the flow. The accompaniment of all collisions between air masses and consequent potentials, is vibratory stresses; as, in a billiard ball when struck there is the main stress causing its motion and the clicking sound or vibratory stresses accompanying and dissipating part of the force of the main impulse.

We must therefore picture to ourselves the stream lines in the higher regions of the air as unbroken by conflicting fluid masses, or figuratively speaking as **solid**, but affected by conditions below so that there is a constant series of elastic undulations in the lines, of miscroscopic and very large amplitudes, and all of temporary character so far as the successive air masses are concerned.

Now if the question came up, how could a deviation or "bump" on these lines, having its origin in a cause far below, be effective for work, I must refer to subsequent chapters and merely say that "stream-line" is a figurative term denoting direction of **inert** flow and whatever causes deviation of this flow requires force, implies energy and ability to do work. For the rest, and merely as a preliminary hint, the reason why a blow struck on the butt end of a chisel is transmitted to its edge and there does work, is also effective in the air; only certain conditions differ and these will be explained to the best of my ability.

4. **Atmospheric Energies.** Those that concern us are the kinetic and potential in actions and reactions of mass movements. As to potential, by this is understood in this reference elastic stresses (local and apart from the aerostatic pressure caused by weight of superincumbent air), incidental to, and caused by fluid movements in their urging each other forward and conflicts with opposing masses and obstacles. Kinetic energy is constantly transferred into temporary potentials, and vice versa, throughout the atmosphere; though with an accompanying dissipation, as has been indicated. The amplitude of the potentials may reach great dimensions, as is shown more particularly by the variations from time to time in the height of the barometric column. If we imagine for instance two winds from opposite directions meeting in a valley banked by high hills, the effect of their collision would be noted by a quite sudden, though for certain reasons, gradual rise of the barometric pressure in the locality. Viewed in detail, the impact would cause gradual stoppage of the "heads" of the colliding columns and transfer of kinetic energy into an elastic stress affecting their "bodies", and indeed all the surrounding, at the velocity of sound and with a diffused intensity directly proportional to velocity of impact and inversely as some power less than the second of the distance from central stress plane. In other words, the arrest of motion would be felt at remote points by a molecular crowding and reaction. After a short time the potential would reach its maximum: part of its force would be continually spent in elevating air against gravity resistance, introducing a positional form of energy to take part in the stress; part in causing an overflow of air over the sides of the valley at angular directions to the original; this would continue until finally the momenta of the winds would be spent, when the remnant positional and elastic potentials would force the "tails" of the columns apart in opposite directions. What is here described in a rough way for the actions and reactions between "grand movements" applies with equal truth to smaller, and when moving masses are not otherwise confined than by surrounding inert air. The illustration, as an extreme, is only given to impart a proximate idea of the variety of amplitudes, magnitudes and time-elements that enter into the mechanics of the problem, as well as the behavior of the clashing masses under consideration.

The kinetic energy of air is of course expressible in the well-known formula $\frac{1}{2}MV^2$, and this truly stands for the work it is able to perform, viz., a unit mass of air, be its dimensions a cubic foot or mile is theoretically capable of transmitting as much energy of motion to other matter as it contains. For moment of impact the same rule may be applied, but with proper qualifications. We know that air in a wind on coming in collision with, say, a building does not act thereon with all its mass. To do so, it would have to have infinite rigidity and elasticity, in which case the building would be like so much tissue paper before it. It acts on it with some of its mass however; for were it infinitely fluid or so constituted that only the molecular film in actual contact pressed thereon, according to mass and velosity, there would be practically no pressure. What part of its mass then acts? The question is easily answered, viz., as much as the building **reacts** upon until the air is overstrained; or, what amounts to the same thing, as much air as is elastically stressed by the stoppage and reaction; or as much air as acts rigidly and as though solid in the impact; as much as is compressed and capable of enduring the strain incident thereto without breaking up in fluid deviations, etc. So, if for any reason one desired to give mathematical expression to the impact force, the mass must be considered at the instant as extending from plane of impact to the nodal breaking point of the elastic stress impulse propagated at sound velocity. These relations may be better conceived when regard is had to the elastic limit of the air, to be given attention directly. The problem, as evident, is complicated by the fluidity of the air and inert air cushions forming in front of the obstacle, etc., and the conditions for fluid reaction must first be understood before anything tangible in the form of mathematical rule can be applied, based on theory proper. In the case of continuous flow against an obstacle, successive masses are reacted upon and in turn overstrained and fluidly deviated. The rigid reactional strain would, so to say, radiate back into the air from the obstacle and flicker in length according to the varying velocity and angular incidence of the impinging masses.

The [illegible]

Considering the essential fluidity of the air, in connection with the ruling principle of least resistance, and that, too, the inertia of the air is the only factor that determines its resistance, contingent on its elasticity to say **how much** air shall offer inert resistance in a given time—that is, we must ignore viscosity in this reckoning as being itself nothing but a function of inertia, and disregard residual affinity and the gravitational bond between the molecules as being altogether infinitesimal and beyond practical significance —it is obvious that no complete exchange of momenta between different masses, in prolongation of the line of direction of their forces, can take place so long as these air masses are free and ready to yield in any direction of less resistance than that directly opposing the given forces. This is of some importance to know, since, with air fluctuating in velocity, it means that in all aerial collisions between horizontally moving masses a vertical component—both fluid and elastic-solid—is inevitable and must as a rule be more forceful upward than in any other direction, since the solid earth reacts and deflects air deviated against it upward. There can be nothing superior to plain logic in determining this, though by simply holding a piece of cardboard horizontally in a wind one soon sees that vertical forces are both active and plentiful. A prolonged pressure of a given force will produce an equivalent amount of fluid motion in the air, but a pressure of sufficient suddeness and short duration will produce an unalloyed elastic stress (as a sound pulse). The kinetic energy of a fluidly moving mass of air cannot be transferred to another and effect a similar movement thereof without a potential condition first intervening, and in this respect there is identity in the transmission of fluid movements from mass to mass and elastic-solid pulses in the atmosphere. But otherwise a clear line must be drawn between these effects, as the following more plainly indicates.

5. **The Elastic Limit of Free Air.** This introduces a conception of rule that I believe is absolutely new in aero-mechanics; and if so, supplies a most important link in the theory of sound, which is now missing though empirically given. It moreover furnishes the basis for all laws governing aerial actions and reactions and is itself founded on deductions from the fundamental laws of motion.

Air in a strictly confined state has no known elastic limit; it may be condensed and expanded by piston action in a tube apparently **ad infinitum.** In the free, unconfined state, considering unit masses within the atmospheric grand mass, there is plainly a limit, though a variable one, depending on this, that the inertia of the air is the only element in it capable of offering resistance, while its elasticity determines **how much** air shall take part in this resistance, contingent, however, on another element, viz., **time.** This follows from elementary principles of impact relations between all material elements, be their states solid, liquid or gaseous. Sound, as well-known, travels through them all and follows the same general law whatever their "states" may be. In this respect it is indifferent whether we consider a solid as having fluid characteristics or a gas as having solid; the elastic propagation is the same, only with velocity differences determined by relations of density to the elasticity modulus. In the propagation of sound waves through any molecularly compact substance the elastic limit of such substance is never exceeded. This is evident, when exception is taken to some rare cases, as in unannealed glass, where the internal stresses are very delicately balanced, and imperfectly elastic bodies, as certain hygroscopic rocks. For were it exceeded, the result would be permanent deformation or displacement in the molecular configurations of the substance—work done which would at once annul the force of propagation—something denied by experience, at least with regard to pure air. As this plainly denotes an elastic limit for air in a free state, it must follow a consistent law. And as air in a free state evinces perfect elasticity and rigidity in the laminar displacements incident to transmission of sound pulses, it behooves to investigate the phenomenon at the seat of origin and determine the rules under which it may so act also there.

For, can it be thought that it should be able to act as though solid and without fluid characteristics in the transmission of sound waves and not also at the vibrating surface producing the waves?

A solid when subjected to a pressure trans-stepping its elastic limit breaks, suffers permanent set or deformation. Gaseous matter yields to such stress alone by fluid displacement of the strained part—moves and thus absorbs the force of the stress. The laws of this action for fluids are deducible from general principles of motion as depending on a time function, and that action equals reaction. The process of reasoning into the particulars of the problem may take form as follows—

Air, being inert, cannot be moved without the action of a force (and force here shall have regard solely to that which takes the form of a pressure); it cannot be pressed upon without being compressed or undergoing strain of a potentiallity equal to the acting force. [illegible] X

Preceding a fluid movement, then, an elastic-solid condition of strain must be effected, and this as involving an elastic displacement, or a localized internal movement, **takes time.** Such time may be of short duration as time is usually reckoned, but still remains time. No movement can take place out of time and air must obey the laws of all matter in this respect. Being inert and elastic, it must first be strained and **react** before it can be moved bodily, or in fact be acted upon. Without strain there could be no stress, no pressure, no reaction. Only in absence of either elasticity or inertia could a mass be conceived moved instantaneously by limited force. It will be recognized, however, that in an impressed strain there is a contraction and internal adjustment of matter which must be considered instantaneous in character, or instantly proportional to the force impressing it. To-wit, in the planes of action, the first film of molecules resists for an instant by virtue of its inertia; this overcome, it crowds on to the next adjoining film, which likewise resists for an equally short time and crowds the next, and so on. In an incredibly short time the inert reaction of a huge mass of air is thus invoked, and due to nothing but that property which is inherent in all matter, viz., its elasticity. The law of least resistance has been observed, and the molecules have moved accordingly, but their crowded state, inertia and elasticity have prevented anything but a greater crowding in the limited time given. With the time and force extended, a new line of less resistance opens up, as it were; the mass is overstrained, detaches itself from the surrounding and moves; the strain vanishes, unstrains, and the force becomes spent in causing the flow.

By express condition, then, it is given that kinetic energy of one moving mass, cannot be transferred to another without a potential condition first intervening, consuming time. The potential condition conducive to fluid movement in the atmosphere may have two forms: (1) a mass may be pushed so to say directly from behind by another, or (2) there may be an indirect "push", caused by a partial vacuum in front. Properly speaking this is not a mechanical difference, but only two levels of potential. In either case time is required before the potential difference issues in work or fluid displacement of the air concerned, and in this intervening time we can conceive of only elastic movements as occurring.

By the principle that action equals reaction, it may be proven that only within the elastic limit can there be transactions between air masses involving exchange of momenta, as indeed holds good universally for such transactions between all matter. For direct action (i. e., without the intervention of another medium) equals reaction between masses, only when referred to any instant, consequently a stress must equal its counter-stress or strain, and if it occurs in the free air it can be due to nothing but its inertia and so long as this effects resistance. As an example, a ball coming in collision with another ball, acts and is reacted upon only during the period of stress while in actual contact. Whatever effects are observed thereafter as result of the collision stand no longer in relation to the systems as action to reaction; at least not mechanically. Thus, likewise, air deflected and moving away from other air or objects that caused its motion no longer reacts on such. In other words, the most elementary considerations prove that unit masses can only influence other units by stress and during the stress period.

By this it is also given that only when the elastic (time) limit is exceeded can fluid effects supervene in air by the action of an impact force. The fact that on account of its essential fluidity this period is generally short for air in the free state when concerned in such transactions, makes no difference, so far as the truth of the proposition is concerned; for the elastic limit of free air is circumscribed by nothing but time, and may now be more exactly defined as the time intervening between the commencement of elastic-solid and commencement of fluid motion in localized impactual stresses.

remember air [illegible]

Now, the time between the commencement of a pressure and fluid motion depends for its duration on two things, namely (a) the **intensity** of the local stress, determined by the impact velocity, and (b) the **extension** of the stress, determined by the dimensions of the plane of action. As a basic proposition, subject to qualifying conditions, it varies inversely as the intensity and directly as the extension; and these factors between them are determinative of the elastic limit of free air. Within this limit reactions are proportional in effect to the stressed masses multiplied by the square of the impactual velocities.

The relation of the intensity to this (time) limit, we shall come to directly. The extension, or magnitude, determines the possible amplitude of action in a given time, and is determined by the area of the plane of action. In illustration, consider a telephonic diaphragm. Its period of vibration may be varied between extreme limits, but its amplitude cannot exceed but a small fraction of an inch, if purely elastic waves are to be generated by it. For this reason it can reproduce any note in the register of sound, but cannot be moved to produce the loud roar of a fog horn; its plane of action is too small. Overstrain—fluid effects—would be the result were the experiment tried. If we were now to construct a similar diaphragm a hundred yards or more in diameter, we should be able to excite elastic waves in the air of amplitudes measured by yards instead of fractions of an inch; that is, by the increased plane of action provided so much more air could be simultaneously acted on that the elastic limit would be extended and sounds might be produced by it compared to which a fog horn would sound like a boy's tin horn. If the diaphragm were a perfectly rigid disc, there would be shearing stresses and fluid movements around and toward the edge when moved, unless confined in some manner as a piston and with a bell-formed outlet for the train of waves; but if the circumferential edge were held rigid and the disc elastic so that it could be bulged to and fro with decreasing amplitude from center outward in all directions to the periphery, we should obtain elastic movements without accessory arrangements, slow or fast, unaccompanied by fluid effects in the free air.

It may be profitable to analyze this matter a little more in detail and the abstract.

(a) **Intensity.** It is quite evident that the time limit for fluid motion varies inversely with this factor; for it is axiomatic that the greater a force the sooner it effects a given quantity of motion. Then, according to this alone the limit extends from zero to infinity; which is saying that an infinitesimal force would never move the air fluidly no matter how long it acted on it, and an infinite force would move it instantaneously. In an intensive sense there is accordingly no theoretical limit; viz., we may conceive a diaphragm to vibrate infinitely slow or fast without moving the air fluidly. But in practice two limiting circumstances come in and qualify this principle so that it has little semblance to its basic form. These may be called the **Critical Amplitude** and **Elastic Momentum.** The latter refers to the momentum imparted to air, so that it continues its elastic motion after the action ceases and will be explained better in a subsequent chapter, in connection with the mechanics of bird flight. As to the former, it appears as a logical proposition from an inquiry into the nature of the intensity. This, namely, is determined by the velocity and the latter by two things—viz., pitch and amplitude, or the number of vibrations per unit time and the length of their excursions to and fro from neutral plane to end of harmonic motion and back in that time. Now a simple inspection must show, according to this, that every sound pitch has a limited amplitude of its own when produced by any given diaphragm and quite apart from any limitations inhering in the diaphragm itself. Thus, if (per impossible) vibrated infinitely fast its amplitude would have to be infinitely small, if fluid motion were to be avoided; and conversely, if moved infinitely slow its amplitude could be infinitely great without causing fluid disturbance. The elastic limit thus determines a critical amplitude for any pitched note from any one diaphragm; which is to say, a given note may be rendered more or less loud by it, but only up to a critical point of loudness; this point exceeded the air breaks down and moves away. In more concrete terms this signifies, that if by experiments conducted under such conditions that the amplitude could be controlled and varied at will, we should find that a given diaphragm could be vibrated with a maximum amplitude of 1-100 of an inch at 100 vibrations per second without producing fluid effects, we should know at once, and find it so, that to vibrate the same diaphragm twice as fast, or at 200 vibrations per second, the amplitude would have to be cut down by one-half to synchronize the pitch with the velocity factor determinative of the intensity. It need not be said that any diaphragm under ordinary conditions conforms automatically to this rule, is limited by the rigidity of the metal and adapted by empirical rule so that it seldom has or can have more force impressed upon it than will cause it to vibrate well within the limits of critical amplitudes which concern the air alone. Also, by confining walls, rendering it impossible for air to escape sideways, the principle is modified; but this last forms no part of this enquiry, which concerns actions in the free air solely.

(b) **Extension.** The elastic (time) limit of air varies directly with extension of plane of action. This conclusion is warranted by experience, and from considering that with increased surface, or plane of action, the distance to which any molecule or molecular aggregate of the strained mass has to go before disruption and fluid motion can take place is increased in proportion. In practice there is, of course, a limit to possible extension, and so likewise to the time for fluid reaction. The extension is obviously the only factor which posits time, the all-important element, in the case; and intensity cannot be considered apart from it. A vibrating diaphragm must have some surface and the extent of this surface determines the time limit, from zero, for a point, to infinity, if we could imagine an infinitely extending surface in air and acting upon it. But the amplitude of the vibrations for any palpable surface being restricted within critical points determined by the intensity, it follows that there is a critical amplitude for any pitch varying as the extension. If the elastic momentum is included in the reckoning, as it surely must, the rule may be modified to read: for a stationary surface acting repeatedly on the same air the elastic (time) limit, or critical amplitude, varies directly as the square root of the extension. In acoustics still further qualifications may enter which have regard to thickness and quality of the material of a vibrating surface, as determinative of fundamental tones. But these finer points need not detain us here, as it forms no part of the plan to include the mechanics of sound and vibratory (insect) flight herein. The reaction to be considered refers to gliding flight, in which "new" air is continually affected—acting and reacting on surfaces of peculiar form and quality. Still, as it is a recognized principle that any vibrating surface has its harmonic scale of possible loudness, determined largely by its extent, in the above may be found the scientific rule for this phenomenon, based on the laws of matter and motion. Some modifying factors enter as stated, in practice (e. g., it would be difficult, if not impracticable, to cause a surface as large as a base drum to emit notes of the piccolo order), but as a basic theoretical proposition the rule holds that the critical amplitude of any sound-pitch varies with the extension; and, conversely, that any extension has its own critical amplitude for any sound-pitch.

Nothing in the science of acoustics that I have seen conflicts with this principle; on the contrary it explains and supplements what seems lacking in that field. It shows, too, among other things, how in collision between grand units of moving air, the planes of action (irregular, of course) may have extents measured by square miles, and accounts for the immense amplitudes and partly for prolonged durations of stress, indicated by barometer observations. Herein is plainly indicated also why there can be no perfect exchange of momenta between air masses in straight lines, since prolonged stress will deviate air fluidly along lines of least resistance.

The principle of elastic limit, it may be noted, does not in any way contradict text-book definitions of a fluid as contradistinct from a solid—that any force, no matter how small, exerted upon a fluid within its mass causes permanent molecular readjustments: it merely emphasizes and gives more definite meaning to what is at the same time recognized, namely that inertia opposition must be overcome—practically the only thing in a fluid, as air, to be overcome—which consumes time, and it gives the rules for the variableness of this time.

A pressure on air compresses it, no matter where and how it occurs, and strictly speaking no other effect is possible (except the resistance to such forced contraction and an adiabatic or isothermal elevation of temperature) so long as the pressure persists or is able to persist before it ensues in fluid motion; yet, as any elastic stress in air spreads in all directions, it is permissible to say that air in the action is also **deformed**.. The use of this term offers occasionally certain advantages and will be employed herein with this implied understanding.

Viscosity ignored, air is capable of restitution from strain to its original form, volume and place, and that too with a force of reaction equal to the action that caused its deformation, provided its elastic limit has not been exceeded; in other words, if it is permitted to react **in time** before fluid displacement commences. I hold this proposition as axiomatic in that it merely follows a principle that is true for all matter. We shall see, however, that it may be subject to qualification. The point is merely brought out here as it forms the pivot around which any **consistent** theory of flight must swing.

6. **Remarks.** It is hard to avoid the thought that if some of the eminent men who have evolved epoch-making acoustic instruments, as the telephone and phonograph, had put in a few hundred dollars worth of their time in thinking out the fundamental propositions in acoustics, many millions of dollars worth of time and material used up in endless experiments and scrapping of manufactured products might have been avoided. Think also of the millions of dollars' worth of "grated feelings" which have been produced by these instruments in the past! A grating sound in a phone or phonograph is due almost solely to the fact that in various ways more force is impressed on the diaphragm than its critical amplitude will permit. And for such to swing beyond its proper confines means simply that it causes the elastic limit of the air to be exceeded, which has as a result instant disruption of the harmonic relations which should always obtain between the diaphragm and the air, the element really concerned. But if non-recognition of this principle has caused untold waste and expense in this field, how much may we expect it to produce in aviation matters, if left as they stand? For, let it be known first as last that the principle of flight is co-extensive with that of sound; whatever laws hold true for one find their counterpart in the other, with modifications that are largely immaterial. The principle of elastic limit runs as a distinct red guide line through the whole domain of aero-dynamics, be the facts to be explained mechanically that of sound, flight or aerial movements. It is a principle that is basic and merely expressive of the immutable laws of motion referred to this subject. By its aid an orderly system may be perceived where otherwise chaos and unrecognized principles appear ruling, as in the atmospheric ocean of movements and energies. Not however until differences of potential caused by electro-magnetic or other influences are better understood, will all the phenomena of atmospheric behavior be entirely intelligible; but this is of but remote concern herein.

What has been the object in going to some length in discussing atmospheric motions, energies and transfer of same from mass to mass is that thereby indispensable premises are gained for subsequent enquiry. We obtain at once a clue to the determination of the conditions for transfer of a maximum of atmospheric energy to another system, which is our main theme, and to harmonious actions and reactions between such systems when juxtaposed. It must be evident that those conditions are identical. It cannot be that air behaves differently, in so far as this question is concerned, toward other elements than it does toward itself? A foreign system introduced in the atmosphere, and to feel at home therein, must be on friendly terms with it if actions and reactions are not to assume the form of hostilities with attendant waste of energy. And, mind you, the atmosphere is a mighty enemy to come in conflict with. It engulfs with an insatiable appetite any force hostile to it in an instant—absorbs it, body and soul, into its huge body. Insignificant, imponderable element that it appears in the small, taken at large it is the most all-devouring of any we can become directly aware of on this earth. Its diet is energy and it eats up, digests and sheds billions of horsepower of this stuff as a daily ration given to it by the sun and earth. An infinitesimal quantity, like a hundred horsepower more or less from an aeroplane motor, is gulped down by it with about as much a sign of distress as that caused a whale when it swallows an infusorium. So we need not worry about the atmosphere. No harm can come to it by any force we may direct into it. Better worry about the gasoline supply. The air would swallow all there is in the earth's bowels in a day had it a chance, and then come out on top with a fresh desire for more. The question is shall we feed it to it fast or slow, or not at all in conquering it? Being, as it is, so well charged with energy, it seems like a real sin to empty more into it than we strictly have to. To conquer it, force is evidently the wrong thing to use. Better perhaps come to terms with it; learn to know it. Things must evidently be made to harmonize with it by conforming to **its** laws, as the reverse of the proposition is impossible. The purest result of such harmony is strikingly exemplified by animals in flight. They conquer the atmosphere truly; make it disgorge its energy for their benefit; we use explosive powers, to pour it in all the faster. Can the moral be read?

III. THE PRINCIPLE OF SUSTENTATION IN BIRD FLIGHT (Outlined)

1. **Preliminaries.** The mechanics of bird flight presents itself essentially as a subject of actions and reactions between two systems—the bird on one hand and the atmosphere on the other—with interchanges of momenta or energies. The "bird system" possesses energy in two forms, kinetic and potential, with attributes of weight, inertia and momentum; and so also the atmosphere. Transactions are therewith rendered possible, and in these the bird is mainly represented by its wings. The relations are as harmonious as possible and have a positive and negative aspect. By positive is here meant that circumstance in the transactions whereby the atmosphere does work on the wings; by negative, the reverse of the proposition or air resistances proper to the bird's progression. Given that the relations are harmonious—that is, that the system supported in the air is susceptible to atmospheric influences of a kind useful to its conservation in opposition to the resistances—it is obvious that the less the negative influence, the less also the necessary positive; or, in plainer language, the less the resistances the less the necessary driving force. Now in soaring flight the curious case is presented, that the element which resists also furnishes the driving power to overcome the resistances; that as a fact, the atmosphere merely does work upon itself, the bird being considered an integral part of it. We may however so express this relation as to say that the resistances represent work done by the bird on the air while the driving power represents work done by the air on the bird; that thus, in virtue of its contained energy, the work done by the atmosphere upon itself in this case is of an indirect kind and by the localized interposition of the bird merely changed to a mode different from what it otherwise would have been. Hence, with a little license, we may say that the more opportunity the atmosphere has of being preponderant, the less is the negative aspect presented; and, therefore, the species in which the negative is the least pronounced, extensively and intensively, is on the whole most capable of soaring independent of its own stored energy.

To illustrate roughly by an example. We observe a buzzard soaring on pinions unmoved by muscular power near the ground in a very gentle wind under circumstances which preclude its receiving much help from the kinetics of the atmosphere. Its weight is neutralized by atmospheric reaction due to its horizontal speed. Now, the air resistances opposing this necessary speed must be balanced by forces in the atmosphere aiding it (else how could it soar?), and the later forces (positive) being demonstrably small in this case, yet sufficient as shown, it follows with logical necessity that the former (negative) must be equally small. A woodcock on the other hand, under the same atmospheric conditions, flaps its wings violently and is incapable of soaring, showing the negative in preponderance, to make up for which it spends muscular power. Bird systems, as will appear more plainly later, are about equally receptive **intensively** to atmospheric propelling power, but **extensively** not so. That is to say, the woodcock may gain considerable benefit from atmospheric (positive) movements, similarly as the buzzard, but the effective area of wing surface that it spreads, compared to that of the buzzard, is so much smaller that it cannot become influenced sufficiently from that source to be independent of its own stored energy, consequently cannot soar like the buzzard.

Now, considering the latter bird, it is clear that in order to explain its ability to soar—and by soaring I mean **directed** sustentation in the air absolutely independent of muscular energy—it is essential to demonstrate two things; viz., (1) that the support reaction requires but very little power for its maintenance, or is in the nature of a static effect, and (2) that its wings are sufficiently receptive to atmospheric power (which we know is available if it can be rendered effective), for supplying what is required.

The first proposition brings up the question of "fundamentals":—How air reactions neutralize gravity in bird flight with so little dissipation of energy. This is a somewhat extensive subject and would require a good-sized volume to itself for thorough treatment, but as the second proposition concerning the application of atmospheric power is intimately bound up with it, we cannot avoid the task of at least outlining the same if later developments shall not seem puzzling and unsupported. This is the object of the present chapter, but it must be taken as merely in the nature of a limited sketch of this most important principle. Whereas, thus, advantage is not taken of opportunities for thorough analyses, of direct and indirect nature, and a methodical progression touching on **all** the points in the problem, enough will, it is hoped, be given to render the results intelligible and plausible to begin with, when as the reader progresses to an understanding of how the "soaring powers" of the atmosphere are rendered effective, he will see the theory of "fundamentals" herein sketched more and more sustained and indispensable to this soaring theory proper. If the one stands, so must the other.

2. **Is the Support Reaction "Solid" or Fluid?** Facts are what require explanation; facts as they are. They are so plain in this case and point so unmistakably to but one conclusion that only the man with distorted vision and warped faculties can fail to see them. The surest sign of a nescient attitude with regard to plain facts is to deny them; find it more convenient to explain them away than to explain them, regardless of the ridiculous consequences often attendant upon such course. Facts relating to animal flight have suffered too long from this attitude of mind by men who call themselves scientific. If we but glance at birds in flight, say a swallow as it skims along any time with the utmost freedom and lack of evident exertion, flapping its wings intermittently and but gently, going now in one direction, now in another, now high, now low, **and all day long**—seeing this, does it suggest great sustained exertion and expenditure of energy? If so, please explain where the energy comes from. The swallow lives on what it catches in the air, and watching it shows that only once in a while does it snap up some little

insect, the fuel for its system. Of the total value of this fuel, 30 per cent only and as a maximum, can be converted into energy producing combinations available for mechanical work, the remainder goes by the exhaust and in the metabolism of tissue renewal, vital functions, heat, etc. Seeing and considering this, I say, does it stand to reason that by the dynamic action of its wings it causes a constant fluid displacement of the air, making it sag at successive points of contact? If there is any doubt on this point, take notice that every unit mass of air thus displaced has weight and inertia, and that it means so much dissipation of energy, so much work done on the air, to so move it; and observe further that this work is in addition to frictional and body resistances proper to the birds progression—energy irretrievably lost to the bird. As when in walking on soft yielding ground we find it hard labor, so would the bird find it—and far more so—were the air similarly displaced by its wings in flight. Plain facts show that such cannot be the case, and reason, mathematical calculations,* irrefutable logic would demonstrate that where the sustentation principle of necessity such as to involve a considerable amount of fluid reaction at the expense of the bird's system in addition to other resistances, flying creatures would not exist. In the economy of nature there would be no place for them.

I should like to go to further length in hammering these conclusions home, but laboratory experiments in their slow, accidental fashion are now beginning to sustain them, so it should not be necessary. Only I would ask the gentle reader the next time he may see a swallow skimming along of a calm day over the blank, mirror-like surface of a pond, if he can find the slightest trace of a ripple on the water or other indications to denote that the air is fluidly displaced by the action of its wings? I have watched much and seen them go so close to the surface that their wing tips often touched the water but never found such to be the case, nor do I believe anyone ever will discover differently.

Now what holds for one species of birds holds for all, and extends to insects. Only a subjective delusion due to the casual experience that rapid motion is generally associated with an equally rapid dissipation of energy stands in the way of perceiving that this does not necessarily hold true in all cases. Thus it has come to pass that because we see the larger birds glide swiftly in the air with the utmost ease and freedom from exertion, we promptly doubt our senses and conclude they delude us, and when we see an insect vibrating its wings at a tremendous rate, we just as promptly believe in our senses and imagine that this involves expenditure of great power. Now the reverse is exactly true. Motion, rapid or slow, has nothing to do with dissipation of energy. That depends on the resistances and how these affect the conservation of the energy of what moves. In the ether of space the most rapidly moving object continues forever with unabated speed, and were we to start an ideally elastic tuning fork vibrating in pure vacuum it would continue its vibrations forever—and (think of it!) in an "ideal" atmosphere, under certain conditions, likewise. As much energy as were expended on this atmosphere by the prongs in their excursions to and fro would be returned to them by the elastic reaction of the air and keep them going forever. They would form with this air a reciprocating, dynamically conservative system, and resistances apart, could not stop. Tuning forks as they are and the atmosphere as it is, they soon come to a stop under the circumstances by generating a train of elastic waves and operating against a number of resistances costing power; but not so soon as they would did not also this atmosphere continually react upon the forks and return part of the energy expended on it in one instant in the next. Bird and insect wings operate on the same principle of reciprocal action and reaction, only with far purer results in energy conservation than is the case with tuning forks having sharp, narrow prongs of rigid metal which churn up the air. But while no theory of flight can be complete without taking in vibratory as well as gliding flight—which at bottom rest on the same principle and are mechanically related to the action of a tuning fork as a direct current relates to an alternating current of electricity, or as a one-sided action relates to a two-sided—here alone the gliding principle will be given attention as it is the only principle having a practical significance.

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*One celebrated mathematician of the last century demonstrated in good faith by figures that a swallow used about 1/13 horsepower in flight. He based his calculations mainly on Newton's immature ideas of the flight principle, and evidently did not consider that the poor bird would have to have at least ten mouths and throats into each of which insects would have to pass as fast as they could be swallowed to supply this energy; that besides its stomach would have to have a super-phenomenal digestive capacity of at least 10,000 times greater than it has, to speak naught of further requirements. To such results lead mathematics if one puts ridiculous data into its formulae! So beware of a person deft with figures; he may be long on these but short on judgment. A grain of sense would have suggested that one pound of swallow could not have the power of 1,000 pounds of horse.

Facts and considerations pertaining thereto, then, we shall conclude sustain the contention that air acts and reacts as a solid in bird flight; and when investigated from a mechanical standpoint there appears to be nothing to gainsay it. The theory of sound alone is conclusive on the point that it **can** thus respond; and by the principle of elastic limit we are in position to tackle the question **how** and its limitations, for such reactions must come within this limit.

3. In the gliding sustentation of birds, two absolutely distinct but coordinate principles of support are readily recognized: (1) the "fundamental" and (2) the "supplementary." These designations are somewhat arbitrary, as what I term supplementary may in fact be the more active and fundamental of the two. The former is, with the larger soaring birds at least, the only active principle when "neutral" air, or air devoid of vertical movements, is encountered; the latter takes part more or less in connection with the application of the driving power, be this atmospheric or muscular. We shall take up the "supplementary" principle as an incident to the illustration of angular functions in a succeeding chapter and herein devote attention solely to that which is fundamental and without which soaring flight would be impossible save under a few unusual conditions of short duration by means of the "supplementary" alone.

4. **The Fundamental Principle of Sustentation.** With as few technicalities as possible, I will endeavor to render this intelligible and show that it differs in no essential respect from that which supports this typewriter on the table; that it arises spontaneously with the horizontal progression of the wings in air and adds but slightly to the resistances to their progression. Printing costs preventing a more extended exposition, appeal is made to some extent to that psychological faculty which is the basis of all reason—the intuition of the reader—both for proof and apprehension of some of the propositions presented. A varied scope for more exact academic treatment will be found for those who have the means, opportunity and inclination for such work. The territory covered by the science of flight is immense.

Two reactions are involved in this principle: (a) the **compressive** (produced) and (b) the **vacuous** (induced). In the analysis of these, unless otherwise indicated, the air is considered as "ideal-neutral." This artificial premise is adopted because, in the first place, the reaction in its pure form pertains to "neutral" air, and in the second, since by considering the air at the same time as "ideal," we avoid complications resulting from the inclusion of frictional, shear and restitutional resistances and it is possible to take up these afterwards and determine their modifying influence.

(a) **The Compressive Reaction.** Consider the curve, Fig. 1, as a cross section of a plane gliding in air horizontally from R to F, and as divided into two curves, E-M, M-T. E-M, the compression surface, encounters inert air which being elastic is compressed and reacts normal to the surface by a pressure with a gradually increasing intensity from entering edge, E, to M, the turning point. This pressure is denoted by the resultant P-1. If not overstrained or deflected, the air at M reacts by expansion on the rear (receding) surface to T with as much pressure as it acted on the compression surface. This pressure is indicated by the resultant P-2. By resolution, the horizontal components of these resultants are equal and opposite, therefore neutralize each other so that there remains alone the vertical components, both in the same direction, viz., upward.

This is the simplest case that can occur and illustrates the main principle by which a support reaction is obtained by insects whose wings are thin, flat, elastic planes, curving very slightly by impact with the air and operate with a combined gliding and vibratory action. It is also the curve presented by the posterior thin margin of bird wings. But it has its limitations, as it permits of practically no thickness to the wings, which of course determines their strength and weight carrying capacity; moreover the curve must be exceedingly easy, otherwise an elastic momentum is imparted to the air which induces a partial vacuum and negatives the effect. So easy and flat, in fact, must the curvature be that it becomes practically indiscernable to the eye looking for it when viewing wings of birds in flight, and, as will be shown later, it comes into play relatively seldom. The maximum depth of this depression in a condor's wing probably does not exceed 1/10 of an inch under normal conditions of flight in which it becomes active. It must be understood that the reaction of the air alone produces this convex curvature, owing to the great flexibility of the posterior part of the wing. The curvature is concave when the wing is not in action. Though not very effective for weight carrying, the reaction produced by this curvature is very important and it is doubtful if any bird could fly without it. It corresponds in one respect to the angle of attack so-called of an aeroplane surface, only here the angle is re-entering and the air attacks the re-entering surface as much as the entering surface attacks it. The whole action should be considered as in the nature of a very gentle and continuous glancing blow affecting successive points but leaving the air in its wake unmoved and as before the blow was delivered. The pressure it produces, besides furnishing a small part of the sustaining reaction, controls automatically the fore-and-aft direction of the wings in the vertical plane—something vitally necessary. One would be rash to assume that because this curve produces a positive deformation of the air by (elastically) deviating its stream lines downward that a similar negative deformation (rarifaction) occurs on the superior surface under all conditions. For effecting this there is required the sinusoidal slope, if caving or tumbling of the air is to be prevented. Fig. 2 gives an idea of what I mean. But these figures are drawn with much exaggeration. I repeat that no such action could be produced with steep slopes and rather abrupt curvatures such as the diagrams might suggest, but quite the reverse.

Much could be written on the possibilities and limitations mechanically of this reaction. The final result, however, is, considering the turbulency of the "real" atmosphere and requirements of conflicting factors, that the surface producing a reaction in this manner must be exceedingly flexible so that in proportion to speeds and impact force it yields, flattens out and maintains a fairly even pressure.

(b) **The Vacuous Reaction.** This is induced by the front and greater portion of a wing and is the main principle whereby support is obtained in "neutral" air. What in the immediate foregoing were found the bane to the extension of a principle, is here discovered of the utmost importance. Instead of the easiest curves, here the more abrupt rule.

Fig. 3 represents a cross section of a bird wing moving at a fixed soaring speed horizontally from R to F; or, it makes little difference, we can consider it stationary and conceive the air as moving in direction from F to R. Action on the air and reaction on the wing to be determined. (Dotted lines represent aerial stream lines.)

The air is split at the cleaving edge C into two parts, one passing underneath, the other above. The air passing underneath along the gliding surface is at atmospheric pressure, which at sea level averages nearly 15 pounds to the square inch. This should be noted as a point of some importance. The stream lines of this air are but slightly affected. Generally a slight negative (concave) curvature is encountered along the front portion, and sometimes (as, in an albatross wing) a considerable hollow space is found for this section. The significance of this is but slight. It causes a succession of small rotations of the air so that the wings glide with a combined roller and slip friction, probably ~~lessening this resistance, and~~ it confers certain structural advantages. It also has its use in cushioning the impacts of air in the bird's travel in turbulent air, aiding its progression (see "c," chaper VI). Where the concavity is considerable, air in the hollow would have a tendency to follow along with the wings and its renewal would be slower. Otherwise atmospheric pressure obtains until the depression surface at the rear deviates the stream lines in the gentlest manner down and up producing a positive reaction, as has been told above.

So far things are simple and this is about all there is necessary to know about affairs on the under surface. Coming to events on the upper surface, we meet a principle in combination therewith that is at once as beautiful as it is astonishing; simple yet infinitely complex when attempt is made to subject all its possibilities and problems to exact analysis.

The deflection surface A in the figure is drawn as a perfect cycloid—"the curve of quickest decent," and the geometrical expression for impacts between bodies of perfect elasticity. The beauty of this curve is that it lifts the air in the fastest possible manner with a gradually decreasing abruptness and at the same time elevates it straight up. Not perhaps so obvious, but so it works out. And what happens according to Newton's Lex I? Air has received an impulse upward and cannot stop instantly, its momentum prevents; yet considering its elasticity and that it cannot move fluidly, what? Only one conclusion: It is deflected elastically and goes as far as the force of its momentum carries it in opposition to the elastic stress, i. e., until these forces balance. This simply means that the air goes beyond the surface; but since the kinetics of its molecules permit of no complete deflection **en masse** at any thinkable speeds, there is formed a partial vacuum on the surface and a plane of compression some distance above it. The center plane of this strain, or maximum compression, is suggested by the line "a" in the drawing. It might in reality be much farther away than possible to indicate in a diagram, but that is inconsequential. Between the surface and this plane (a) a geometrically graduated diminution of the strain obtains, thus on the surface itself we have the most vacuous film of air. Now it is to be noted, the air has received an impulse (elastic momentum) carrying it up and the restitutional force of its strain as soon as the momentum is overcome restores it again down in the same place with as much force as it was deflected. Some time elapses in this whole action, and as during this time the surface advances, the returning air meets it on the reverse slope B. This slope is sinusoidal ("the companion to the cycloid") and as it recedes with reference to the air that adiabatically speeds on to it, it is capable of dampening the impact force of this air to nil; stop its descent without rebound; abstract all its energy. In a succeeding chapter the conditions for transfer of kinetic energy from air to a material plane to further its progression will be discussed, and from that it will be noted that the conditions here shown are ideal for transfer of **all** the energy of the deformed stream lines as they close in on this surface in the manner indicated.

actually the [illegible] normal

A point of some difficulty here enters: Is any part of the strain energy incident to the elastic momentum sent upward in space as a sound pulse and thus lost beyond recovery? I have given the point considerable attention and think the conclusion right that the elements are wanting for the formation of a regular wave train in this action; that on the contrary (unlike the bow waves formed by a ship) the elastic impulse is recalled in time in its excursion before a series of nodes necessary for oscillatory movements can be initiated by what amounts to a gradually dampened self-interference; that thus the whole of the elastic-positional potential is available for restitution, minus dissipation due to causes to be enumerated. (Some energy is always translated into sound in bird flight, but the quantity thus lost is small in case of soaring birds and does not involve the main reaction.)

All actions so far have been considered as coming within the elastic limit of the air, as this is obviously essential. This condition granted for the moment, the question is: What is the resultant of this whole action? Proper analysis should disclose.

Air deflected elastically in the manner stated has work done upon it and reacts on the deflecting surface (A) with a force equal to the deflecting moment; each air particle impinging reacts normal to the surface and for an instant at least is deflected according to incidence of impact; but the beauty of the stream line formation incident to continuous impact of compacted air with a cycloidal wedge as it travels forward horizontally is that the resultant course of the air is, via a parabolic path, for all particles involved perpendicularly upward, while the **primary** impact components are both horizontal and vertical. Plotting of the movement of any molecule resultant on the factors prescribing path of least resistance reveals this. Thus but a part—more or less than one-half according to the wedge curvature, but we will here say one-half—of the deflecting reaction causing the formation of the strain line "a" is negative, i. e., downward; the other half is horizontal and opposed to the travel of the wing, i. e., retarding. Similar relations obtain when we view the impact of the descending air on the receding surface (B). Here the components are also vertical and horizontal, but the latter accelerates the travel of the wing as much as its counterpart in the deflecting action retards it. These equilibrating forces are suggested by the arrows P-3 and P-4, Fig. 3.

A certain quantity of air is lifted against gravity resistance in the action and must be included in the work of producing the strain. The weight of this air and the distance lifted is inconsiderable. The laminae displacements would determine this and depend upon variable factors such as speed, amplitude and dimensions of the surface. The gravitational reaction of course restores the energy spent in the lift when the air settles and does work upon the wing. The components of the impact forces concerned in these transactions with gravity are therefore added to those due to the aerial straining and unstraining.

Now the gist of this is that air is lifted and forced into strain upward and yet reacts only with a part, or say one-half of this force downward on the surface forcing it upward—a seeming paradox opposed to mechanical principles. But, mark well, it is not asserted that air can be thus displaced in **one** direction without an equal reaction in the opposite; only it is denied that this reaction can **as a whole,** under any circumstances, affect the surface **primarily** causing the displacement in this manner. If we throw a rubber ball on a surface inclined to the horizon and it rebounds therefrom and strikes another inclined surface which by its inclination deflects it straight up vertically, assuredly the component reaction **downward** on the first surface is not equal to the whole lifting force perpendicularly **upward** since another vertical downward component has been added on its impact with the second surface. Only the resultant of the primary impact can equal the whole vertical lift, ignoring air resistances in this case. Similarly, the a-line is an elastic adjustment of the air taking place after the reaction on the A-surface and is the result of the primary impact resultant as this is resolved into the primary component (P-5, negative) and secondary deflection components due to and involving the contiguous inert and elastic air which takes part in the reaction proper and is responsible for the apparently missing half or remainder. Thus we have, via an indirect route, an equal and opposite reaction, but the resultants, not the components, are solely concerned. This is an important point to consider since it diminishes the negative lift in the transactions for establishing the vacuous zone, the element which induces the difference of potential between upper and under surface and causes the buoyant reaction. The resultants resolved into components are suggested in the diagram by the arrows P-3, P-4, and P-5, P-6. The two later are negative but in their sum not to be compared to the potential difference between the vacuous zone, Z, and the aerostatic pressure bearing on the under surface. Intensively these components (P-5 and P-6) may be greater for the short horizontal sections they affect, but extensively—and that is what counts—there is no comparison, the vacuous surface being far greater than these sections combined. The difference may vary from zero up, according to speed, width of wing, curvatures, and is restricted by the elastic limit of the air alone.

The net effect, then, is an upward reaction of the air bearing on the under surface as a resultant of the whole action, with the retarding forces neutralized by equal accelerating forces. The always-present aerostatic pressure alone acts on the under surface, but not being balanced by an equal pressure on the upper surface, we have a "lift." Paradoxical this may seem, but it is as strange as the ball-and-nozzle puzzle? Perhaps it is, since the latter paradox rests on the same physical principle, as do all other fluid phenomena of like nature that find application in the mechanical arts (as, the trompe, injector, etc.). It may be that these have been referred to their proper fundamental cause though I have not happened to come across any that really goes to the bottom in the premises. Matters are explained in vague terms, as, e. g., due to "lateral inductive action of fluids," etc. Therefore, as this principle (though in forms not so readily recognized as identical) plays a most important role in the mechanics of bird flight, I will state (or re-state) herein the true basic cause for this behavior of fluids. When we pull a pendulum from its neutral resting point over and up to one side and let go, it swings on its pivot back but does not stop at the neutral point; its acquired kinetic energy carries it almost as high over and up on the other side. It is a case of potential to kinetic, and vice versa. If we compress air or a gas in a tube, we have potential energy which similarly may be translated into kinetic (and, vice versa, from the latter condition again into potential). The neutral point of this gas is atmospheric pressure; but if it is allowed to expand freely in any manner it cannot stop short and cease expanding at that point. As a swinging pendulum, its acquired kinetic energy carries it way across, which means attenuation below atmospheric pressure. In this produced—or "induced," words do not matter—vacuous state it obviously causes the surrounding air or other media of greater potential to close in to fill the void, and such adjoining fluids are carried along, with perhaps some surging to and fro under certain conditions. This happens in all cases when air is blown, even as we blow it from our mouths or with a fan; the impetus quickly carries it across the neutral point from compressed to vacuous and thus in a double manner affects the surrounding. Similarly when a quantity of explosive is set off in the open. Its original volume is 1, the neutral point may be 4,000 volumes and it goes beyond to 16,000 volumes or more and gives great impetus to surrounding air besides. Windows, if smashed, are hence just as apt to break outward as inward; in fact more so, since while at first there is tremendous compression, in the next there is a very high vacuum and a surging return action more potent for such destructive work. Provisionally this action has been termed "elastic momentum" herein. Obviously it is a characteristic of the behavior of all fluids under such conditions, even water, though it apparently is no more stretchable than compressible and will cause air to enter it to do the stretching for it, as in the trompe, or cause an almost pure vacuum (infinitesimally minute) as it overleaps the neutral point some little time before issuing from a nozzle, thus rendering the ball-and-nozzle puzzle explicable.

In the case before us the same principle is clearly active. Air meeting the cycloidal A-surface is compressed by the impact, rebounds and, perforce, is carried across the neutral point—as logically as that the pendulum does not stop at the neutral point when swinging. The action is continuous and accounts for the buoyant reaction sustaining the bird.

(NOTE:—To the electrician this, by analogy, should immediately suggest a theoretical solution of many perplexing problems connected with Hertzian wave action and innumerable electro-magnetic paradoxes: To the physicist a clue to the determination more particularly of the nature of the luminiferous ether, by virtue of a theoretical indentification of magnetism as a positive and negative stress in the ether accompanying electronic displacements. For example, as a current kinetically rushes across between the potentials in a conductor it would invariably trans-step the neutral point of equilibrium and induce stresses in the ether parallel to but across the dielectric, manifesting itself by deflection of the needle. Knowing what magnetism is in one case, we may infer as to its nature in another. Thus the attraction of a permanent magnet might be caused by ethereal stress produced by potential electricity in a static condition locked up by counteracting atomic forces in the proper medium. Knowing what magnetism is, we should be in a fair way to know all there is necessary to know concerning the ether.)

But, coming back to the induced vacuous reaction and incident "lift" caused by a bird wing as it cleaves air, observe that this is not in the nature of a **perpetuum mobilum** principle, and for the very simple reason that this resultant pressure or "lift" (P-7, Fig. 3) is neutralized by gravity, the weight of the bird. If this resultant by a speed excess becomes greater than the weight, the bird is immediately elevated against the resistance of gravity, but always at the expense of its momentum, nothing else, until the forces are again in stable equilibrium. Instead of something magically produced from nothing, we behold but an example of an elastic-solid compound strain induced in the air by gravity, just as the latter force induces an equal and opposite strain in the solid earth when the bird alights on it with its feet. It owes its induction to the gliding speed and cannot exist without it, to be sure, but coming down to the bottom of things this can make no difference. The strain in the air is dynamically conservative, i. e., the forces which induce it constantly renew it, otherwise it answers all the descriptions of a static reaction. The air reacting as though solid in the whole transaction, the progression of the pressure is not unlike that of the action of a rubber tired wheel rolling on the ground with constant compression and expansion stresses neutralizing each other. It is in the nature of a mechanical chess problem to figure out exactly how the pressure of the weight of the bird reaches the ground in the case, seeing that the bird's weight must be added to that of the atmosphere and increases its local density in a way; but no more so than to determine this for the later types of French monoplanes which have a vacuous reaction contributing to their support far exceeding that directly produced by a concomitant angular attack on the air by the under surface. In view of the power they consume, however, it is very doubtful if they are so adapted as to receive much, if any, return action of the air on their receding back slope.

To avoid further arguments and mathematics in proof of the possibility of this form of reaction—which would involve weight and quantity of air affected, speed of wing, certain time functions, etc., and which at best merely proves its **possibility**—the attention of the reader is invited to the published results of Mons. Eiffel's experiments, which show with surface forms similar to bird wings a suctional lift exceeding the direct reaction in proportion as nine to one. Eiffel did not obtain bird wing results; no, for that at least a glimmering idea of the laws underlying their action is a **sine qua non,** apart from a lucky stroke of accident which would have to be repeated through an unlimited series of harmonic scales, as will be seen from what follows. In this connection it may be remarked that an investigator attempting to explore the aerial reactions on such surface with sensitive pressure recorders might be at a loss to discover the return action of the air on the receding surface, since the pressure vanishes promptly as it touches this surface, the air transferring its elastic momentum to the surface exactly in ratio as the surface recedes. His apparatus might be incompetent to tell him of it unless some clever precautions were taken, or indirect methods adopted.

That this principle is intimately bound up with and conditioned by the elastic limit of the air follows as a matter of course. If I had success in making this notion clear in the preceding chapter, there is easy sailing ahead.

In the first place two things must be identified with this principle, namely **pitch** and **amplitude** in sound phenomena. A glance almost should tell that pitch corresponds to the horizontal gliding speed while amplitude to the maximum (vertical) thickness of a wing section. Consequently, as holds for sound, these two things, viz., gliding speed and amplitude of surface, determine the displacement velocity, which again determines the intensity and therewith the time for the commencement of fluid disruption of the air. However, this holds alone for configurations large or small of identical curve characteristics. Another and third variable governing the intensity is brought in with the displacement curve which has no exact counterpart in sound phenomena. This curve, as evident, may be abrupt or easy and therewith also affect the displacement velocity determinative of the intensity in relation to the two other factors, hence diminish or extend the elastic (time) limit. We shall consider these factors in turn and show how they predicate an harmonic infinite speed scale for any reaction.

Referring to the section in the preceding chapter on the elastic limit, it will be recalled that a critical amplitude was determined for any sound pitch which varied with the extension of plane of action in free, unconfined air. This rule also holds here; only, by reversal, it is more convenient to speak of a critical gliding speed (pitch) for any amplitude, as it is the speed and not the amplitude (thickness) which is here the more variable. Extension in a wing refers to the fore and aft width. It necessarily also subsumes extension in length, but since this determines merely the dimensional magnitude of the reaction it may be considered to enter but secondarily into the problem and can be taken up later. Then, taking the extension in width for any fixed displacement curve and amplitude—which combination may be termed a **characteristic speed configuration**—if the speed is gradually increased from zero up, a point is finally reached when two things happen: (1) the critical amplitude for the given extension is reached, the elastic limit is exceeded and fluid movement commences; (2) therewith the restitutional force of the air is disrupted, such as remains is slower in responding, with result that as the surface at the same time travels faster, the air falls some distance back of the sinusoidal slope, i. e., beyond recovery of its energy for accelerating the travel of the wing. Now this is a thing that will, or must, happen no matter how the three factors determining the intensity are combined, since the primary factor is the gliding speed and this cannot go beyond a point of harmony with the others.

But while here the pitch of an ordinary sounding board and the (gliding) wing speed are identified, it is necessary to make one distinction. The soundboard continually acts on the same air while the wing as continually passes to "new" air. By the principle of elastic limit it should then follow that the wing would be able to act on the air in proportion more intensely as the horizontal speed increased, since with increased speed the time of action is equally shortened for the air affected. And by this it should be expected that there would be no critical speed limit for a gliding surface. Truly this must be affirmed, but it is negatived by another factor—the elastic momentum—which says that in proportion as the displacement speed increases the air is hurled away more violently, if not farther, and its disruptive point reached so much sooner: whence a limitation is established determining a critical speed for a gliding surface, identical in principle with that which determines a critical amplitude for a stationary surface; only, whereas the critical amplitude for a stationary surface is directly proportional to the square root of its extension, with a gliding surface it must vary in simple, direct proportion thereto. This is of course a very important point of difference.

An inspection of this principle in the light of the laws governing the extension of the elastic limit therewith, and at once, reveals that any characteristic speed configuration has the same critical speed limit no matter whether large or small. But the reaction depends on the amplitude, and when everything is varied in direct proportion, the quantity of air displaced is varied as the square of this dimensional factor, while the intensity remains constant for identical gliding speeds. As we may take it for granted that the characteristics of a bird wing are harmoniously combined, this simply shows that if such wing were doubled (say) in extent with identical curvatures, etc., it would support in an identical manner and with the same results four times as much weight at the same speed as the smaller and have the same critical speed limit. I have never found anything in fact or reason that contradicts this assertion; on the contrary every phenomena of flight that I have had an opportunity to look into seems to support it when due allowance is made for compromises effected by the influence of biological principles.

Now as to curvature, and by this is meant more specifically the displacement curve, since the recession curve adapts itself thereto automatically when other functional factors harmonize. In the first place it should be remarked that no flat-surfaced wedge will, or can, displace the air elastically into the form a symmetrical strain line and without fluid disruption; the curve-formed wedge is essential. Of all possible curves for this purpose the true cycloid is the most obtuse, and any of more abrupt form is not permissible. It forms the starting point and is the basis of all reckoning in this reference. Between it and an absolutely flat surface there is an infinite scale of other curves of more easy lines. The cycloid is at the same time the fastest and slowest of all imaginable curves for entering into and wedging the air upward into a strained condition with attendant vacuum. Fastest ~~because~~ in the sense that with a given gliding speed it displaces the air upward faster and produces a greater vacuum than any other curve; slowest because it produces a maximum intensity of reaction with the slowest gliding speed and therewith sets the limit for the critical speed at the lowest point. The more a curve deviates from the true cycloid, the less its vacuum with a given speed; the less also the reaction and greater gliding speed is required to sustain a given weight. This is permissible under the elastic limit, since the intensity reaches its disruptive point more slowly the easier the curvature. Thus, **pari passu** with the flattening of the curvature the critical speed rises in proportion, but with the requirement of a characteristic extension of the fore-and-aft dimension (width) to also keep pace with the incident point of fall of the air. This is to say, the more easy or flat the displacement curve the faster must be the speed of the plane for the sustaining reaction to equal one with greater abruptness of curvature; but therewith also the recession slope (B, Fig. 3) must be displaced farther back which necessarily requires greater surface width. The vacuous zone is of course therewith extended in the same proportion, but as the degree of vacuum is reduced in ratio as the extension is increased things fall in accord. Accordingly, we may construct planes, like wings, with characteristic speed properties suitable for any reasonable speed, say up to a practicable maximum of 300 miles per hour, but none of them will leave the earth with their burden, by the "fundamental" principle of support alone, till this speed is nearly reached. While at the same time we may, if we choose, construct surfaces that lift at surprisingly slow speed but which cannot be driven at much greater speed than that sufficient for lift with any reasonable expenditure of power; for the resistances beyond the critical point for its characteristics would soon pass from the square to the cube and any power above, owing first to the vanishing of the accelerating component and, secondly, to the increasing disruption of the air beyond this point. In a properly designed aeroplane a motor developing 25 horsepower should drive it and its occupant at a speed, as I reckon, as high as 300 miles per hour, so long as the motor had nothing but necessary—unavoidable—resistances to overcome; that is, provided its characteristics both of surfaces and body called for this speed, which is absolutely permissible; but if its characteristics call for but 20 m. p. h. as the critical limit the same motor developing a thousand h. p. could not drive it horizontally at 200, much less at 300 m. p. h. No paradox is involved in this assertion, only common sense if one will only look into it. To be sure, the vacuous zone and lift increase with speeds beyond the critical point and part of the energy is recovered by the added elevation of the system incident thereto, but that is another matter and in any case work is done for which there is no adequate return.

The question then is, how do birds sustained by a gliding reaction vary their speed, in view of the limitations indicated? In the first place I must direct attention to the "supplementary" principle of support, Chapter V, which must be read in connection with that occupying us at present in order that a comprehensive idea of the whole problem may be had. Secondarily, I may state that I have made thousands of observations and never found that the individual species did vary their "air-speed" a great deal, though there is no doubt that they can do so if they wish and can afford to waste energy. Observations prove that they maintain **as a rule** a constant rate of progression with reference to the air, evidently neither far below nor above the limits prescribed by their characteristics for best economy. Considerable difference is shown between **different** species in respect to speed rate, which, however, is accounted for when their wings are examined in light of these principles. Thirdly, the soaring speed of any individual bird—and by this I mean here the least air-speed at which it is supported by the fundamental reaction—is considerably less than the critical for extended wings, i. e., its wing-spread has a marginal capacity above that absolutely required, thus permitting by itself of a little speed variation within economical limits. But, fourthly, the beauty of the mechanism of bird organs is that it admits of a limited extension of the critical speed, something that would be impossible in a fixed surface like an aeroplane as contructed. Birds are thus able to play different (gliding) speed tunes on their wings though the register of such notes is restricted and, as I have reason to think, not quite harmonious within the given limits. This ability depends to some extent on their requirements in mode of living; thus the soaring birds most able to vary their air-speed are the falcons and hawks. When they wish to fly fast they flex their wings, making them shorter and broader, and this at the same time distends certain elastic ligaments connecting shoulder and wrist joints, which ligaments form the basis of the front edge for this section, with result that the entering wedge is flattened and made sharper. One should examine their wings soon after they are shot to see the point. Fig. 4 gives a diagram of such wing when flexed, in which **A** is the shoulder joint, **B** the wrist joint and **C** the ligament referred to. Observe that the fore-and-aft dimensions determining the distance of travel for any air particle from front to rear must change to a limited extent by such flexure. It seems also that they are able to shift the relative positions of the radius and ulna bones and therewith ease the curvature for their requirements, with a concomitant adjustment of the rear flexible part. It is entirely within reason to predict that the aeroplane of the future will be similarly adapted for playing different speed tunes, but they will not be of such simple description as they are at present. Meanwhile they may be made to play one tune without discord and that will be quite an achievement.

Obviously no fixed mathematical rule can be given for relations involving an infinite series of different curves, ranging from the pure cycloid to the almost flat: but by experimental determination of the relations for a few curves and their true dimensional characteristics, approximate values may be obtained by integration for any curve. There is of course no curve which has not its proper and mathematical extension characteristics. The density of the air will not affect this, but the relation of density to elasticity will; but this is a point of merely academic concern. The rule here simply holds, that when the characteristics for any curve configuration is determined, the amplitude square determines the reaction for any soaring speed.

Besides the fore-and-aft characteristic, certain length characteristics are also indicated by study of the flight principle. To-wit, it is important to prevent air, always seeking line of least resistance, from deviating sideways from a straight line fore and aft with attendant waste of energy. For this reason bird wings always have greater length than width and their width narrow down to almost a point at the tips, the thickness (amplitude) always bearing direct proportion to this taper as well as characteristic curvature. Thus, any cross-section of a bird wing is a perfect replica of another section of the same wing and only to be differentiated dimensionally. The weight carrying capacity of wings is obviously largely determined by this extension, as with more spread a larger area of air surface is acted upon in a given time. Nevertheless this has no **absolute** significance. If say the bones of a condor's wings could be endowed with sufficient strength, there is no reason why its wings could not be twice as long and thus support twice as much weight under identical conditions of amplitude, width and gliding speed. Nor, under the rule given above, is there any reason why they might not be only half as long as they are and support twice as much weight with the same gliding speed, provided the amplitude and its characteristic width extension were doubled with the same curvatures. Only in this latter case their positive aspect would be decreased in proportion, to the detriment of the wings' capacity for receiving atmospheric driving energy and the relative proportions of length to width would be such that air would tend in marked degree to deviate sideways fluidly with great loss of energy. Hence, and from measurements sustaining the point, it must be concluded, though in a restricted sense, that there is a characteristic length and taper demanded for any characteristic speed configuration.

So far the gliding speed has received but little attention. It is of course most important, as on this depends the support reaction primarily. Within the elastic limit, or up to the critical point for any configuration, the reaction varies directly as the square of this speed. The gradient may be fast or slow, from zero up, according to the harmonics of the surfaces, but this rule is invariable. On this factor depends the rate of change to "new" air and the intensity of the reaction in direct proportion; hence the square. But mind well, no rule is laid down for any reaction due to this speed factor outside of the elastic limit. After the critical point is passed things become indeterminate, depending on proportions obtaining between elastic-solid and fluid effects. The rule can only follow the various gradients of the harmonic scales of proportions, when the action comes within the elastic limit.

The body of a bird is round and in the form of a double cone of easy entering and re-entering curvatures and lines. See Fig. 12. It is the only form that permits of progression in the air with a resistance due to no other elements than enter into the resistance of the wings at speeds maintained. A critical speed limit pertains to it likewise and is deducible from the same general principles. In the progression of a bird's body the air is elastically wedged apart and deformed in all directions into an infinite number of ring-formed, longitudinal-transverse strain lines, opening and closing as it speeds through, with constant work done on the air and as constant return work done by the air on the bird. Instead of a linear elastic displacement, we have here a conical, whence the critical amplitude for characteristic bodily extensions is proportional to the square of linear extensions of identical harmonies. The amplitude of the body being measured perpendicularly from the longitudinal axis to its thickest point, this means simply that the maximum diameter of such body may have an extent eight times greater than the thickness of a wing section in proportion to its harmonic extensions. One may see from this how futile it would be to improve the ballistic properties of a projectile by forming it as a bird's body. With its great speed the proper harmonics would not be attained until its length became about equal to or even greater than the gun. Ballistics has nothing to learn from the science of bird flight, nor vice versa.

All birds have minor defects, such as protrusions of the beak, eyes, feet, etc., causing deviations from the best stream-forms, and everything may not be mathematically true to infinitesimal extremes, but assuming a geometrically perfect bird according to the principles herein outlined—one inherently balanced, rigid and dead—and introducing it into an "ideal-neutral" atmosphere, what would be the result? Given an initial start, it would soar around the earth forever in the same horizontal plane. Gravity would have no more power to stop it or drag it down that it has over the moon, so long as its momentum were conserved. If the initial speed were greater than sufficient for soaring, the excess momentum would be absorbed in elevating it to a higher plane, whence it would continue forever. Given less than its soaring speed it would instantly take a downward course, exchanging potential for kinetic energy, until its proper speed were attained, and then continue forever in that lower level. Given an initial soaring speed in a purely "neutral" atmosphere, it would take a downward course, exchanging positional energy for kinetic in proportion to the resistances, but maintaining its soaring speed until reaching the ground.

5. Resistances to Progression. This lands us at the bottom of things. From this basis an intelligent edifice may be reared and causes and values established for all phenomena connected with soaring flight. We have assumed unnatural conditions, and they are by no means trifling. The real atmosphere is far different from our fictitious product, but the basic elements in the latter coincide with the real. In the atmosphere "as it is" a number of resistances enter that prevent the conservation of the momentum. These may be classified, but to assign to each its proper co-efficient with absolute accuracy is impossible. The necessary data are lacking. It is possible only to approximate their value, knowing their nature. Those that hinder the ideal results given, and to oppose which requires power, I should enumerate as (1) friction and shear-stresses near all surfaces exposed to the air, (2) restitutional stresses in the elastic movements connected with the constant opening and closing of stream lines, (3) minor vibrations transmitted into the air, incident to the elastic movements, (4) imperfections of various nature causing minor fluid movements, and (5) stream-line movements of the air not coinciding with the stream-form of the body and wings of the bird. This last has a more positive than negative aspect, and forms the main theme of this work, so may be counted out for the present. As to the others, a rough estimate may be made, based on frictional or viscosity co-efficients such as exist. Taking the large turkey buzzard, its weight is about 5 pounds, but this has no bearing other than involving the restitutional resistance incident to constant renewal of the counter-stress, which resistance is a constant independent of the speed and directly proportional to the weight. The minimum soaring speed of this bird is about 12 miles per hour. This means air-speed of course and is maintained at this low rate under conditions in which the "supplementary" principle of support is co-active. I have reason to think that about 25 m. p. h. is necessary before the air will support it alone by the "fundamental" principle. So considering the resistances to this speed and assigning two-thirds of the total to Nos. 1 and 2 and one-third to the remainder (not including No. 5), a result is shown which should not be surprising to the one who has thoughtfully contemplated the apparent resistantless progress of this bird. I get a value of about one-eighth foot-pound second—two ounces constant horizontal pulling strain to keep this bird sustained at 25 miles per hour. No finality is assumed for this result, but probably it will be found by more refined methods and experimental check as not so wide off the mark. It should be a matter of only short time when physicists and mathematicians, properly equipped, turn their attention to this subject and arrive at results of more certainty; for assuredly here is a subject of infinitely greater practical significance than many of the abstruse problems in science now receiving so much attention. Knowing with some degree of certainty the power required by one of these wonderful birds to drive them with a support reaction, we should at once have a basis for determining the co-efficient of ignorance which now enters so largely into the artificial product and find means of reducing and eliminating this instead of using tornado-producing apparatus to cover it. A goal and high mark of efficiency would then be set for which the practical engineer could head and maybe in the end reach.

6. Comparison of Support-Reaction Sustaining Bird and Aeroplane. If the question were asked, how are our present-day aeroplanes supported considering the principle enounced which shows that at bottom only an elastic-solid resistance of the air can afford such support, the answer is clear: There is no element in the air capable of offering resistance other than that which takes an elastic-solid form. Air cannot be pressed upon without being compressed. But of inert air there is unlimited quantities which may be overstrained; i. e., acted upon too long and intensely. Air cannot be overstrained and moved fluidly without resisting, and if a modicum of the power used in thus overstraining it shows up in the form of a support reaction, this is hardly to be wondered at. An aeroplane has one positive aspect and that is its propeller actuated by motive power. By its pull frictional opposition and the work incident to overstraining and putting tremendous quantities of air in motion is accomplished simultaneously: support and speed is the result, to be sure, but at the expense of tremendous waste. I am not prepared to deny that aeroplane surfaces with their curved backs have a limited positive aspect. by which air deflected and causing a vacuum reacts back to further their progression: on the contrary, I think it is so if not overspeeded. Still no one seems to have suggested it. The aeroplanes of today are the result of refinements based on experiments founded on vague hopes, not on knowledge of ultimates. By accident and elimination it were to be expected that some product should be evolved showing a trace of the properties of bird wings; of evidence that experiments have been guided by knowledge of the air and its basic laws there is no trace. The best product I have so far seen any account of shows such overwhelming co-efficient of ignorance in its proportions and make-up that its motor wastes at least ten times as much power as should be necessary. Comparisons are proverbially odious, but the truth must be faced; and the sooner the better. Progress tramples on vanity and shows no mercy in its peculiar way. To it, it is absolutely indifferent whether one's nose is flat or straight, whether the name that attaches is Rheuben Smith, John Doe or Isaac Newton; whether one's birthplace is Tasmania, France or Japan: only the narrow-minded human egotist attaches any importance to such accidents. It has regard to the whole, not the one. So it is useless to waste any pity on the pioneers; they did as well as their lights permitted. Destined they are, however, to the limbo of oblivion in the relentless onward march of progress. Their product is an evolution from the kite, not an induction from bird flight. By substituting in a kite for the string and running boy a propeller and motor, enlarging the product sufficiently, adding a seat and some primitive elements for guidance and equilibrium—presto! we have the wonder of modern times, the aeroplane (as it should not be). The genesis of the latter from the kite is more than evident: viz., Hargrave box kite—Lielienthal, Chanute gliders—the internal combustion motor—some literature and theory—Wright and Voisin Bros. aeroplanes! Without the wonderful motor this substitution of power for knowledge would have come to naught. One can only compare this product to birds' organs by saying they stand to each other as a thunderclap does to soft chamber music; as ear-splitting discords to fundamental harmonies; as a farmer's log-drag to a resiliently supported easy-running rubber-tired vehicle. But in point of fact there can be no true comparison. I hope to amply demonstrate that they relate as negative to positive. An aeroplane may look quite genuine and bird-like in the air, but so does a counterfeit coin look natural in the palm of the hand. Mechanically, and beneath what we see, they are as different as night and day.

But if due regard for truth, and disregard for convention, compels the utter condemnation of this artificial product, how much credit is nevertheless not due the originators who in the face of negative science and its dicta, as represented by Newcomb and others, proved the impossible possible? A good thing evidently these pioneers had not the same good judgment as these abstruse arm-chair scientists. They have by surmounting heaps of most unjustified scientific and popular prejudice blazed the way for greater things to come.

~~The present crude product is not a reflection on the originators who had but little scientific ability; it reflects sadly on science itself which allowed such discordant product to insinunate itself into the air when such models existed showing a better way. It should forever prove that the negative in science has no place there and can only operate as a drag on the positive. Science may doubt and investigate, sift good from bad, but never say "No." Science should have investigated to the bottom these phenomena which have gone on right under its nose long before the advent of the gasoline engine and thus prevented such fool-killing contraptions from having seen the light of day. It has so far taken but casual notice of it, perhaps under the impression that it classes with perpetual mobilism or like. (I have had experience that justifies my remarks.) The conquest of the air may be worth a few paltry lives, but there is a limit and that limit is not clearly discernible as things stand and if they are allowed to so stand. As no bird was ever known to lose his balance, suffer breakage of his wings in the air, etc., so there is no reason why we should not fashion equally efficient and safe organs for ourselves. But so much for the present as result of comparing incomparables.~~

5. The Negative Function of Quality. But now, since innumerable experiments have been made and all kinds of mathematical hieroglyphics employed to arrive at the best possible result, why this great discrepancy? I think it can be described with one word—QUALITY. Lack of quality in the surfaces to harmonize with the air—the air "as it is." Therein is found the main reason why no aeroplane has ever been supported and flown with anything but remote resemblance to that of a bird from a mechanical standpoint. Were the atmosphere "neutral," or similar to that found in wind tunnels, etc., in aerodynamical laboratories, good and well, everything could be worked out stiff and rigid with due regard to harmonic principles, and a conservative reaction would result. But since the atmosphere is a seething ocean of moving masses with constant deviations and "bumps" on its stream lines, the stiff surface would now present one side to attack, now the other, and in all cases air would be broken up with dissipation of energy. Just as a springless wagon with steel tires does work in breaking up stones, etc., on the road surface and is retarded accordingly, so do our present-day aeroplanes break up air; only far worse. The air is elastic and highly fluid, so does not readily give evidence of this by shocks and jars, but we may be sure it is going on all the same. Else, what becomes of the 50 to 180 h. p. used? If we smash through something that is uneven and thus even it out by force, work must be expended. Air will not spread out and adapt itself willingly to that of rigid surface striking it at great speed; no, on the contrary it will oppose it with all its inert strength, and in yielding will absorb so much power as were expended in causing it to yield.

For accomplishing the results indicated in bird flight there is required that the surfaces instantly adapt themselves to the stream-lines of the air, since the latter cannot be made to adapt themselves to the stream-form of the surfaces without expenditure of work. This can alone be accomplished by quality—elasticity and peculiar mechanisms connected therewith, as so beautifully illustrated in bird wings, where quality and harmonic proportions are combined into a true system. These adaptable features are so great in a bird that even its body automatically conforms to aerial stream formation, and its progress is largely as though the air were devoid of movements. Regard to the fundamental principle of support moreover demands that the surfaces adapt themselves instantly and automatically to all inequalities in the air; that the pressure be spread out evenly along their whole length in order that no point of the air be overstrained, and that the air pass in a straight line from cleaving edge to trailing edge. If I know the air right, this cannot be accomplished to absolute perfection by any kind of quality; there must be numerous occasions when the "inequalities" of the air are too great or abrupt and no surface would be adaptable enough; hence it can be concluded that resistances from this source are introduced even in bird flight. But it is the function of quality to minimize these effects as much as possible, and this must be termed its **negative** function. The moment, however, the negative influences of atmospheric movements are reduced to a necessary minimum, there arises automatically as it were a **positive**—a selective principle—which so far counteracts this particular negative as to overbalance also at the same time the four other factors of resistance previously enumerated. This means that the bird (or aeroplane when similarly adapted) soars without using its own stored energy.

From this we may immediately take for granted that certain characteristic qualities are inseparable from other requirements of atmospheric laws: just as the springs and rubbed tires of an automobile must bear proper proportions to the weight they carry and are essential to good running. Here perhaps is encountered the most difficult point in the whole flight principle. For by what standard is proper quality to be determined? It may be replied by degrees of stiffness and elasticity according to calculated pressure distribution and elastic responsiveness of the air under average speed conditions, and in this some mathematical rule may be found. The point had best be determined experimentally and left more to the artistic feeling of the constructors than exact rule; at least at first. By bracketing results, final perfection will come. There is this obvious rule, however, that may guide us; namely, taking it for granted, as we must, that bird wings are as perfect as possible, we could transfer all their characteristics, such as form and proportions by pantographic enlargement and proportionally apportion and embody qualities in addition by measuring pressure deflections. Much caution would have to be used, since birds have a limited ability to vary certain elastic features and it is by no means certain that flexed and stiffened in death their wings would have the same characteristics in this respect. If we had a 25-pound condor for the purpose, spreading ten feet of wing surface, and it were required to construct identical artificial surfaces to carry 400 pounds, then as the reaction varies as the square of characteristic dimensions, we should obtain surfaces of a combined spread of 40 feet. If everything were done true, and essential mechanical features to control angular inclination of the surfaces also incorporated, this artificial product would soar, and it would soar with the identical speed and under the same circumstances as the condor. **A priori** this is given, but more convincing proof will be given as we proceed.

IV. ON THE LAWS GOVERNING TRANSFER OF ENERGY AND OTHER QUESTIONS OF PERTINENT IMPORT

Before it is possible to go specifically into the problem of how birds benefit by atmospheric power, it is necessary to have the proper concepts of essential conditions.

1. First to state the problem: While it is recognised distinctly that in the fundamental support reaction there is a negative and positive aspect—

one in which the wing does work on the air and the other in which the air returns and does work on the wing—yet due to inevitable resistances the negative is in preponderance, necessitating another positive, or drive, as a counterpoise for the conservation of the momentum. This counterpoise must be found in the air itself, since facts so demand. The problem is to find it, determine its nature, and prove its utility for the purpose. Muscular power is necessarily excluded from the discussion, except when clearly indicated.

2. I shall not enter into negative speculations other than saying that atmospheric electricity or magnetism can have no direct part in furnishing this drive. The surfaces, if dielectric, may at most generate infinitesimal quantities of static electricity by friction under certain conditions, but this would operate as a resistance, not a drive. Langley's view that fluctuations, purely horizontal, of moving wind masses could furnish the drive will not stand the test of reason. It involves hypo spatial conditions foreign to mechanics. There is wanting a medium of resistance, or a fulcrum, such as furnished in a kite by its string, for horizontal movements, whether fluctuating or steady, acting in the aggregate as a positive; whereas the bird has only a plumb, vertical string attached to it—gravity—which is the only thing that can furnish such fulcrum in its case.

3. No matter how or where one searches, there can be found but one cause and that is fluid and elastic-solid movements having a vertical component. These are abundant in the air, as was the object of Chapter II to show, and their potentiality for work is enormous though diffused. As to their becoming available for work of the kind demanded, that involves considerations to the selective power of wings and the basic laws governing transfer of this kind of energy. The former concerns specific mechanisms and qualities and will be worked out in Chapter VI., the latter is taken up in these preliminaries.

4. A bird in the air needs but two forms of energy, viz., that of **position** (gravity potential) and **kinetic** (horizontal velocity of its system.) These are requisite under all conditions and any "prime mover," whether muscular or atmospheric, must be translated into one or both of these forms to be of any use to it in the conservation of its system as opposed to that of the atmosphere. The one is as necessary as the other and they are interchangeable. The necessary positional energy is quantitatively indeterminate; a bird may soar high or low; but its position measures the reserve power at its disposal in pure soaring flight. The kinetic is restricted within economical limits, as appears by reference to fundamentals, so that any excess quantity thereof beyond the instantaneous needs is immediately translated into the position reservoir, whence it may be used as required for the conservation of the momentum. One will see the similarity of this principle with that governing the planets in their orbits, and it is almost as automatic in operation when one examines it closer.

5. Air must move to do work or move something else, so its energy is in the kinetic condition primarily. But for such energy to be capable of transfer to another system a potential condition must first intervene. Nothing inert can be moved or stopped instantaneously by a limited force; nor can an increment to the momentum of an already moving object be effected instantly. A potential elastic stress is a **sine qua non.** So we come back to the law of elastic limit enounced in Chapter II., which prescribes that transactions involving exchange of momenta must take place within this limit, and therewith

air may be treated as though solid with due regard to its limitations in that respect.

6. The laws of exchange of momenta between solid bodies may be perfectly familiar to the reader, but by way of refreshing memories, some typical cases are subjoined. Merely to denote them by mathematical formulae is thought illsuited. Illustrations are better, as they appeal more directly to the understanding. We may use for this purpose billiard balls, and to further simplify matters, consider their elasticity **ideal** and that no energy is dissipated in vibratory effects in their impacts.

Case I. Complete Transfer of Momentum From One Ball to Another: One ball striking another of equal mass, fair and without rolling, comes to a dead stop and the other continues with the same speed. The point is that the first ball must stop entirely, otherwise there could be no complete transfer.

Case II. Incomplete Transfer: One ball striking another of smaller size is dampened in its progress, does not stop entirely, and yet the smaller ball continues with greater speed than the larger ball had before the impact. The kinetic energy (MV^2 or $\frac{1}{2}MV^2$) remains the same after the impact as before when the sum of the contents of the two is considered, only shows up in the form of greater velocity in the smaller ball though it has not become impressed with all the energy of the larger. The reason why it is not wholly impressed is found primarily in the time element; to-wit, the elastic impulse is so fast that the inertia of the smaller ball is overcome and it separates from the larger before it is entirely stopped. (The action of a water ram is based on the same principle, of large mass versus a smaller.)

Vice versa, and for the same reason, a smaller ball striking a larger rebounds and therefore transmits to the larger ball but a portion of its energy.

The energy is there but is incapable of translation in its entirety in these cases. Could the action be sufficiently prolonged, the greater sluggishness of the larger ball, or the less of the smaller, would be no hindrance and complete transfer could occur. This would be feasible to a limited extent by interposition of suitable cushioning elements that would operate in effect to stretch out the time of action in·the respective cases.

In collisions between two balls of unequal size moving toward each other, the smaller ball must always gain at the expense of the larger.

Case III. No Transfer: One ball striking another that is rigidly secured against movement, or better still, conceived as immeasurably greater in size, rebounds with the same velocity with which it struck. The moment of impact is doubled, but the ball does no work except upon itself in reversing its direction.

Case IV. Imperfect Transfer: One ball striking another that is more or less viscous, brittle, flaccid or inelastic, spends part of its kinetic energy in deforming, heating, breaking up or causing effects other than imparting its momentum as a whole to move the other ball. The effects produced are a mode of motion, but not the kind demanded.

Case V. Serial Transfer (balls of equal size): One ball striking another on the near end of a series of balls laid in a straight line and touching, if its impact force acts in prolongation of this line, does not move the first ball struck nor any other but the last which continues with the speed of the ball that struck. The same action is illustrated when a hammer blow is transmitted from one end of a stick to the other.

If we include vibratory and viscosity resistances in the reckoning, complications ensue. For instance, it is readily seen that the greater the difference in mass the less is a smaller ball capable of moving a larger by impact force, until at some indeterminate point it is altogether incapable of impressing any but vibratory motions on the larger, which are quickly converted into heat by viscosity resistances. This has, however, little bearing on the problem in hand, though its importance is immense in other fields.

7. Air locally affected by impact obeys the simple rules indicated in these illustrations, even though differentiated by the fact of being an indefinitely extending body. Only, as has so often been insisted on before, it is essentially fluid and only capable of acting as a solid within restricted limits. In order that it may transfer all or part of its kinetic energy in any given case, its progress must be stopped or dampened; and this is a **sine qua non,** as it is for solid balls. Moreover it is demanded that it be not broken up or caused to move in the opposite direction, since all energy absorbed or diverted in this wise becomes unavailable in furthering the motion of something else. As time is a factor in all its actions and is limited, it is essential that it act against a resistance it is capable of overcoming in the limited time at its disposal.

8. **The Principle of Least Resistance** is the most helpful guide in investigations of phenomena of motion that can well be imagined. It asserts that if a force acts at random against movable matter, the quantity of work or motion it produces is inversely proportional to the resistances opposing it along the several paths presented for its action. Thus along numerous paths for its possible action work may be performed along all such paths in unit time but never in equal proportion unless the quantity of movable inert matter determining the resistances is equally distributed. Naturally quantity of work is at the same time dependent on, and proportional to product of magnitude and intensity of the force in any given case. In its boarder and more generalized form, however, this principle is a postulated conception and warranted only by the recognition that no infinite forces are at work in this universe as opposed to finite resistances. It is the writer's intention to show its signficance in other lines than the present: How by its aid one may obtain a basis for reasoning into the initiation of motion of the most diverse character; as, how the angular motion and rotation of the earth on its axis was brought about and is today sustained against resistances (tidal viscosity opposing axial motion and ethereal viscosity probably opposing the orbital); how forces are capable of acting to produce cyclones, whirlpools, tornadoes, etc. It opens up a new territory in mechanics which has reference to what may be called self-initiation of motion—how matter may so act and react upon itself, without reference to other material systems, as to move in space; for example, how the "Mexican Jumping Bean" moves in any direction without external organs and without reacting upon other systems in producing its motion, how a cat manages to turn itself in the air, how a spinning top lifts itself by reaction upon itself from an inclined to a vertical position, curving of baseball, the magnificent drifts of whole galaxies, etc. It of course does not imply a "lifting oneself by the boot-straps" or production of motion without transformation of energy from one form to another, but it means just what is claimed, that, e. g., the sun was caused to revolve on its axis by forces acting from within itself and on itself, as may likewise be asserted for the earth and similar bodies. In soaring flight we meet the same principle when

it is considered that the bird forms an integral part of the atmosphere in a mechanical sense and that the phenomena it presents is in the final analysis nothing but the action of matter upon itself. But although this is undoubtedly the proper view of the case, it is impracticable to develop it along these lines without first correcting certain unsatisfactory premises in mechanics as now taught. An acceptable explanation of soaring flight may be rendered without digging to the very bottom of things and so larger questions involved shall be deferred.

The point to be understood in connection herewith is merely that the atmosphere cannot so turn upon itself as to produce the curious phenomena in question without the bird offering a line of resistance against which its contained forces may so act as to produce a dynamic effect of the kind specified, since such forces, though having direction, are free to turn and act in any direction without leaving the air.

9. But coming back to our illustrations of transfer of kinetic energy: When a billiard ball strikes another, there is a pause, an instant, when the masses are motionless, all kinetic energy having been transformed into a potential stress acting with an elastic, and so to say, explosive force. At least, even if there is no instant in which **all** the kinetic energy is thus transformed, it is essential that all partaking in the transfer be successively so transformed, since the balls are not infinitely rigid and tenacious, and no matter on this earth has such properties. Hence in all translations of kinetic energy from one material system to another, both a time-interval and an elastic-potential stress are necessary concomitants. Air moving in a free state must of necessity behave similarly. It must in the first place meet something that resists its progress before it can exert itself, secondly, it must transform its kinetic energy into an explosive condition (elastic stress), thirdly, it must meet a resistance which this explosive force is capable of overcoming, otherwise it acts statically, i. e., potentially capable but under the conditions not capable enough. Accordingly, it may in its free state perform work (move something), or it may not—all depending on the nature of the resistance it meets or whether it meets a resistance at all. The less this resistance up to a given point and the more the potential condition is protracted, the more work. From this ground work bird wings and flight must be read.

But to furnish still another example that may help to give a clear idea of the conditions for transfer of such energy with a maximum efficiency. The reader may have seen on the vaudeville stage certain performers who can throw an egg high up in the air and catch it on a porcelain plate without breaking it. I have seen several such but only one who had the trick down to perfection. He could throw an egg six or seven feet up in the air and catch it on the flat surface of a thin, fragile porcelain dish without even sound being heard and instantly thereafter, without touching it, toss it up a foot or so when the collision on return would break both egg and dish. The same performer could throw a rubber ball similarly up in the air and catch it on a hard surface without the slightest rebound, and with a receding movement of not more than six inches. (I was told he had broken up over 10,000 eggs for a large bakery in Germany to learn the egg trick!) Now, this furnishes an example of transfer of kinetic energy, stoppage of motion, that is significant; for air is just such a thin-shelled solid, easily broken as an egg, and more so; and it is moreover as elastic and easily bounding as a rubber ball, if not more so. To dampen its progress without rebound and break-up, there is accordingly required a receding response on the part of the system that is to be receptive to its action. The surface stopping it may be inherently elastic and yielding, or it may be rigid but otherwise sufficiently receding; in both cases, like an egg, it may be made to deliver all or part of its potential energy without being broken up or deflected.

Considering a moving unit of air as a system coming in collision with a material plane, then there are three possible results: (1) It may, if the plane yields readily enough, impart its momentum thereto entirely and remain molecularly intact, without set; (2) rebound intact, or become elastically deflected with as much velocity as striking; that is, if the plane is not yielding to the impact—possible alone when an elastic impulse strikes, as a sound wave that is reflected like an echo; (3) turn upon itself and break up fluidly; also invariably accompanied by an elastic rebound—a result that may occur in elastic-solid movements of great amplitude and in fluid movements when the plane does not yield at all or insufficiently to be impressed with all the available energy.

The first of these comes wholly within the elastic limit, as does the second; but the third is a mixed proposition and it will depend on circumstances how much energy is, or may be, translated in that case, since there is overstrain due to a too protracted and intense stress. If the plane is unmoved entirely, there is of course no transfer; if one-third of the energy of impact is transmitted to the plane to either move it or add an increment to its motion, then of course the other two-thirds are spent in deflecting and breaking up the air due to overstrain, ignoring viscosity losses; and so on in all cases of partial overstrain. But, as evident, the unit mass may also yield up part of its energy without overstrain, as when a wing cuts through an extensive movement and merely lightly interrupts the progress of a small portion touched. Indeed this may be considered a common rule in bird flight, as almost all fluid movements are extensive and the wing in its swift cleavage can only dampen such to an infinitesimal extent. Further attention will be given to this point later.

10. To enter into a quantitative estimate of the atmospheric driving power available for birds in flight, is impracticable. Only this much is certain, the velocity of the vertical components of moving air bear direct ratio to the horizontal on an average, and the kinetic energy of air is proportional to the square of its velocity; which last applies to vertical fluid movements whether occurring in horizontal winds or when due to heat. In elastic-solid movements the amplitude square measures the driving power, but it will altogether depend on the amount of surface exposed and cutting off such impulses to say how much they amount to quantitatively. There is but one good rule to go by here, and that is that there is practically an unlimited amount available in the air and continually added to it; and the area of the surfaces combined with their **receptiveness** to available impulses determine the **how much.** As kinetic energy implies mass as well as velocity, there can be no other rule for estimating the mass taking part in the action than saying it is proportional to the moving mass **reacted** upon by the wings at their rate of transfer to "new" air. Such action proceeds with the velocity of sound into adjoining layers and the rate of transfer depends on the length of time a wing section takes in passing a distance equal to its width. Furthermore it has relation to the intensity of the stress, depending upon the velocity of impact and abruptness of stoppage, under the principle of elastic

limit. Only as much air can take part in the reaction as is not overstrained to the point where it has relative motion away from the surface stopping it.

11. The question next is in order: How is this transfer of energy effected in bird flight under these rules? It is demanded that aerial forces act either to elevate or increase the speed of the bird, or both (comp. Sect. 5). The speed must be maintained at all times, since bird wings have no parachute possibilities and no force acting purely to elevate the bird avails. It is obviously essential that the air attack the wings, **causing them to yield**; the reverse cannot be allowed. An aeroplane designed to attack the air, kite-like, would be pushed back by the action of any vertical movement, consequently is inherently unsuited for reception of atmospheric power to further its progress. Vertical aerial impulses may at best make the air "harder" as means for support and enable it to ascend faster, at the expense of horizontal speed, or they would enable its surfaces to skim through the air with a less angle of attack and thus on the whole be of some use in diminishing the waste of motive power. Still this is, in the proper sense, negative; positive receptiveness to atmospheric influences requires other conditions. To imagine that birds presented a similar angle to the air and yet were pushed forward by aerial action would be tantamount to imagining water run up hill of its own accord. No; an angle exactly the reverse of that of the kite obtains in bird flight. As walking when analysed presents a principle of continually prevented falling forward, so bird flight in principle is a continually prevented fall downward, the bird being restored to position as fast as it falls on the whole and average. The point is plainly seen in the question: Does the bird push its wings or do the latter pull the bird? The wings pull of course, unless some occult power were at work that would explain how the bird did the pushing. It has neither a propeller in front nor in rear of its body, nor apparently does it suck itself along with its beak. The **onus** lies with the propounder of the view that wings are pushed up-hill-like in order to sustain the bird. There may be some little excuse for one thinking that a bird in flapping its wings rapidly presented the portion of the surfaces nearest its body kite-like to the action of the air while the tips acted propeller fashion, but when a soaring bird is viewed as it floats along serenely and restfully with constant speed for hours and days all excuse for such conclusion vanishes. Moreover, I can say that I have carefully watched for just this point and found that on the whole and average the trailing edge is higher than the cleaving edge. The only trouble here is that the observer is readily subject to delusive appearances, and if he wishes to see the obverse a bird will surely accommodate him at times. The truth is, that now the bird pushes its wings, now the latter pull the bird in flight evolutions, and since it constantly changes its direction and performs "banked" turns, one has some difficulty in telling just what occurs at any given moment. Furthermore, one is generally forced to view these things from any but a favorable point of observation; seldom does a soaring bird either come close enough or on the same level with the observer. Then again the trailing edge may seem, and actually be, below the horizon while the main reaction has a forward component at moment of observation; stream-lines constantly change and no bird rests on the same point long. A bird pushes its wings only when it exchanges a surplus of kinetic energy for potential, but such surplus it has in all cases obtained by this that the wings have done an excess amount of pulling at some previous time. When the bird pushes

its wings in rising to a higher level then it certainly holds them (at times but not always or necessarily) with an inclination that may look like that of an aeroplane surface in the air, still this is often mere appearance; the wings attack the air in the case but the method of attack is kite-like only under certain conditions to be described, and then seldom wholly so.

However, no more space need be wasted in arguing this point. A kite-like action for wings is indefensible under usual flight conditions. Facts and elementary principles of mechanics join to prove that water cannot run up-hill in absence of a force so directed as to cause it to ascend; neither can wings be pushed forward in up-hill fashion and drag the bird along with them in absence of a force so directed as to push them forward. Moving air to act on a wing to impel it forward must have a suitable angle for attack. With an aeroplane it is different. It has a body that does the pulling and so the supporting surfaces may be held to depress the air with a brake-like effect. The only thing to be noted in this connection is that wings act on air in such way that it responds with practically unalloyed solidity and the resistances are so small to the progression that the angle of fall is almost indiscernable to the unaided eye. From observing the buzzard, I conclude that the angle at which it descends in maintaining a minimum soaring speed is in the neighborhood of 2 degrees to the horizontal. This when verified by others must be viewed as the strongest proof of the principle of support given in the preceding chapter, namely as showing how insignificant really the resistances to its progression are.

V. ANGULAR TRAVEL OF BIRD WINGS AND THE SUPPLEMENTARY PRINCIPLE OF SUSTENTATION

1. As indicated in the preceding, angular functions obtain in bird flight as they do in aeroplane flight, only certain matters are of necessity reversed. What an aviator would call a negative angle, we shall be compelled to call positive. This results merely from considering that air attacks and drives the wings whose normal functions are to sustain as well as pull, whereas kites and aeroplane surfaces are pulled or pushed by a separate positive and attack the air so as to drive it.

Referring to Fig. 3, it presents the aspect of a bird wing when "pushed" in neutral air and thus supporting weight. No angular functions properly pertain to it; it is simply going along with its stream-form (line of cleavage) coinciding with the natural stream-lines of the air. As the air then is neutral, so is the angle. This is undoubtedly an aspect as a rule presented by wings more or less, though seldom wholly so. A drive is needed to force the wings forward against inevitable resistances absorbing power and air must have a slanting surface to act on to furnish this drive, which is absent in this figure. An upward gust of wind might elevate the wings under the circumstances but not push them forward. Three angular relations may then be identified for bird wings, viz: (1) the **Angle of Progression,** (2) the **Angle of Recession,** and (3) the **Angle of Fall.** The first two of these pertain to the relation of the surfaces to the air, the third to their relation to the acceleration of gravity. Describing these briefly:

(1) **Angle of Progression.** Identical with that usually assumed by an aeroplane in attacking the air. Relation between cord of surfaces and line of progression. Component reaction, upward and backward. Used by birds

for "braking," transferring energy to the air in retarding and stopping their motion, for assisting the induced reaction in taking care of centrifugal force in making abrupt turns and for maneuvering in play and quest of food. Always with wasteful effect, hence not the normal. The negative of this angle—component reaction downward and backward—is quite impossible in bird flight.

(2) **Angle of Recession.** May also be termed the driving angle, to denote the incident angle at which impinging air strikes the surfaces and impels them forward. It is identical with the angle of attack assumed by wings in the down-stroke in flapping. Component action, upward and forward.

To understand it properly, one must visualize certain component relations—viz., (1) that a mass of air through which the wing cleaves has proper direction in space upward, shown say by **a**, Fig. 5; that (2) the wing section considered, E-T, has direction **b**, here for convenience assumed to coincide with the horizontal. Assuming the length of these lines (**a** & **b**) to measure the respective velocities, then we have **a-2** as measuring the vertical component of the air's travel; hence, drawing the parallelogram, we have **a-3** as representing the relative direction of approach of air and wing, and the angle (**Ø**) between this line and the surface becomes the angle of incidence of the impinging air. By preference it is called the **angle of recession** as denoting the function of forces that recede and are transferred by impact; thus in the onslaught of the impinging air, the surface retreats in the horizontal direction indicated by **b** and away from the air that strikes and due to the striking force of this air.

(3) **Angle of Fall.** This may be defined as the relation between median plane of cleavage and the horizontal. Impinging air masses form their own most suitable angles for delivering a glancing blow and any wing-section therefore may have a slightly different angle to that of other sections of the same wing with reference to the horizontal at any one instant. The undulating plane joining the infinitely numerous lines of cleavage thus formed may be referred to as the "plane of cleavage" and may be represented by a flat plane denoting the mean for the entire wing. This angle is expressive of the component force of the weight acting as a fulcrum for the driving force. While so acting it is of course positive. It may also be neutral and negative, but in the latter case it must not be confounded with angle of progression previously defined. It becomes negative when incident air has a downward trend, the action of which is evaded. As it is possible for a wing to cleave air which at one point of contact has an ascending trend and at another at the same time a descending, one section of a wing may have a positive inclination to the horizontal while another has a negative. This is not of normal occurence, because at the usual height at which soaring birds fly eddying currents, etc., are sufficiently extensive to include the whole of such small surfaces. When this does happen however, the air acts and impresses its motion almost solely on the positive side. This question will be dealt with in detail in the succeeding chapter.

2. **The Supplementary Principle of Sustentation.** From the standpoint of our "fundamentals," it will be realized at once that the inclusion of angular functions complicates things in general. But a very small component of the force of the impinging air acts as a drive, hence the greater portion of the impact force is statically counteracting weight, i. e., producing no motion of the bird system unless an excess quantity is absorbed in elevating this system. Placed alongside of, or superposed on our "fundamental" principle

therefore is this other, and it is, in a sense at least, entirely independent thereof. To reconcile these with each other is however not so difficult.

In the first place it is evident that this new principle is entirely competent to take charge of the whole burden of support, relieving the fundamental (compressive-vacuous) reaction entirely under given circumstances. The circumstances are two, (1) either that the air acts and reacts without fluid motion, thus that the vertical velocity of the air may be the least possible considering its limitations, or (2) that it acts with fluid disruption making a greater vertical speed necessary to prevent the bird from losing position.

Were the first case possible, then, referring to Fig 5, in a proportional representation, cosine (c) of the angle of fall would be expressive of the static sustaining pressure and sine d, of the dynamic component of this pressure (the drive). The cosine would moreover express the rate of transfer of the wing section to new air, thus the duration of the action (pressure) for any air particle passed over at a given rate of horizontal progression. In a question of work accomplished by the driving force therefore this time element would have to be given consideration, standing in proportion to the sustaining force as the sine to the cosine. Now, if the component of sustentation (c) were equal to the force of gravity, obviously the progress of the wing would be horizontal as indicated by the line b and the fundamental principle of support would have no possible way of functioning. One might think for an instant perhaps, that in view of this aspect of the wing, it would encounter inert air on top which would react to depress it; and so would truly be the case were the air "neutral" and bird wings resistant to such pressure, but the air is assumed to be ascending, while the wings glide horizontally and by virtue of their peculiar flexibility incapable of resisting such pressure; hence the air is interrupted in its upward travel not alone by compression on impact with the under surface but also by attenuation above in consequence of its momentum and elasticity not permitting instant stoppage. Therefore the resultant pressure equals the difference in potential between the stress of the air on upper and under surface; and so far from encountering a resistance, the upper surface meets air that recedes from it faster than it approaches it under the conditions. With this understanding we need be concerned alone with the mechanics of the impact pressure, since the negative thereof by reversal of a few terms amounts to the same thing.

But now, were this sustaining force and drive obtained with constant fluid disruption or overstrain of the air, under the second proposition above, the same proportions and rules would absolutely apply, only we must give the air greater speed upward so that its action nevertheless shall equal the gravity reaction. On this assumption, it becomes a matter of indifference what kind of surface were used, how great its extent, etc., we could always in a purely theoretical way imagine the air to have sufficient velocity for the purpose. And here take well notice—and this point is of the utmost importance—any work spent by the air in breaking up, or fluidly or elastically deflecting or displacing such air is not at the expense of the bird system or wing in this case, but solely a matter affecting the air. Here we have a receding surface, one on which the air **in virtue of its own velocity** and force acts, and it is exactly the contrary of a progressing surface, such as presented by an aeroplane advancing and by **its velocity** acting upon the air. So, if besides furnishing the static force for the support of the bird and the energy to drive it horizontally, the atmosphere thus also is caused to act and do a modicum of work upon itself (in changing its direction) this is no concern of the bird and subtracts nothing from its energy. The bird can afford to spend liberally of what is not inherently its own and costs it nothing; just as in our society those who by birth or sundry accidents of success secure a commanding position need not work or produce but may spend with reckless abandon what comes easily and gratuitously. Herein may be found precisely what makes the atmosphere the inferior subject of the bird who by its superior means contrives to take advantage of it; and this difference in angular travel is also what makes a Wright aeroplane a system inferior to the atmosphere which nicely contrives to absorb from it enormous power as a toll merely for permitting it fairway in its domain.

However, in practice it makes a great deal of difference whether the wings cause much or little fluid displacement of air acting upon them; since the more work the air does on itself the less it is capable of transmitting to the bird, the greater the velocity such air must have and the fewer must be the occasions when soaring it possible. Besides this, under average conditions the bird meets a great deal of neutral and negative air in its travel and then must fall back on the fundamental principle for support, exchanging stored positional energy for kinetic sufficient to counteract the resistances. Accordingly, the more it can benefit in a given time from ascending air the more it becomes independent of its own stored (muscular) energy in maintaining itself in the air.

It appears thus that these two principles of support, while independent of each other in one respect, are mutually interdependent and supplementary in another: now one may be preponderant in its influence, now the other; sometimes one alone and sometimes both taking shares. In order to fulfill this condition to perfection the wings must cleave the air with the least possible angle of fall and be instantly adaptable to function one way or the other. It may profit then to square this new principle with atmospheric laws and find out approximately the conditions under which air may impinge and act with a maximum effect in furnishing this kind of support and drive. The observed facts are that in flight the wing planes are held nearly horizontally in their progress in turbulent air, when the drive is active, and that the under surface is nearly flat, or slightly curved.

The action concerns air impinging on a receding surface, but we may first consider briefly the action on a progressing surface, since this has been, to some extent, determined by some very costly experiments and so should be some check on theory. These experiments show that the center of pressure on a surface inclined to a current of air coincides approximately with the center of the plane when inclined at more than 45° to the current. When inclined at decreasingly smaller angles the center of pressure advances toward the front edge until at very acute angles it retrogrades toward the rear. Let the line E—T, Fig. 6, represent the cross-section of such a plane moving with an inclination in direction indicated by the arrow s. We will further suppose this plane to be indefinitely extending toward the observer and away from him, thus that the air must pass in a straight line from front to rear and not deviate sideways. The air acting upon it has one limit, the elastic; the plane two, front and rear edge. The plane may be further conceived, divided by an imaginary line centrally so that we have a front and rear part. If the pressure is equal on front and rear parts, then of course the center of pressure coincides with the center of figure. This as said happens at very obtuse angles (over 45°). The air then, complying with the law of least resistance, passes in part over and partly under the obstruction. But let the angle be small, say 20° or less, this law compels it to pass wholly underneath. The air directly affected is the stratum in the line of progression of the plane having a thickness equal to the sine of the angle of incidence of the advancing plane. The top part of this stratum, or the film of air passing directly underneath from the front edge, is the only air that can come directly in contact with the surface and this film is deviated more than any other, accordingly subjected to more stress which it transmits to inferior layers at sound velocity. Such being the case, it is the only air that need concern us and we may determine its behavior by reference to the proper factors. Being inert and elastic and contiguously related to inferior air, it cannot be instantly deflected at the front edge; first it must suffer compression which consumes some time; and since the plane advances in this time, overstrain takes place at some point removed from the front edge. We may mark this L on the figure and consider it to fix the elastic limit of the air in this case. (This point must not be confounded with the center of pressure, though it determines the relative position of this point in conjunction with other factors.) The action may be analysed by reference to basic principles and modifications considered afterwards. Now, two things determine the elastic limit—the intensity of the pressure and its plane of extension. The intensity at any point varies directly as the angle; only small angles compelling air to pass wholly underneath are considered; so according to this factor alone, decreasing the angle displaces the disruptive point backward in direct ratio. It varies also directly as the velocity of progression of the surface; accordingly the disruptive point on this account advances toward the front edge as speed is increased. The more conclusive factor in the premises, however, is the extension of plane of action. Were this conterminous with the extension of the surface in a case such as this, we should have the proposition that no matter how broad or narrow the surface the disruptive point L would always be at the same relative distance from E and T at identical angles of inclination. It would then follow that the reaction increased as the square of the surface width and indicate that broad surfaces were preferable to narrow, but for the requirement of a characteristic length to prevent air from deviating sideways.

These are basic rules and did air indeed behave accordingly aeroplanes and kites would be very efficient and such matters as center of pressure, etc., could be easily settled. Now air does strictly behave according to these rules, but the factor which we have termed "elastic momentum" comes in and modifies matters so that it might be hard to discern the basic rules in the premises. It does indeed upset things in general, in that it affects the extension of plane of action by which the elastic (time) limit is determined. It must be understood that "plane of action" does not necessarily mean the whole of any surface but only such part thereof as is capable of **acting** by a pressure. If anything hinders the **whole** surface from partaking in the action, then the elastic limit is determined alone by **the active part** and so much diminished. With a stiff, flat plane advancing into the air, it becomes clearly impossible for the **whole** surface to act by a pressure on the air; for at L and beyond the air is deflected, overleaps the neutral point, and becomes attenuated—the very contrary of what is required. The rear portion of the plane to be of any use in adding to the extension of plane of action should have the important function of confining the air and act by a pressure on it, thus preventing the initial break and deflection of the "solid" air. Air must be considered to behave substantially as a fragile solid in questions of impact, viz., a little break initiates and paves the way for a larger; therefore whatever hinders the initial break makes it so much more difficult for the more explosive disruption following to occur and the action is prolonged. With the rear portion prevented from taking part in the action by the induced negative spreading over it by the action of the front part, it is not so remarkable that the center of pressure advances toward the front as angles are diminished, in spite of the fact that another factor, the lessened intensity, tends to work it to the rear at the same time. If such a flat plane were extended indefinitely, there would be formed along its surface alternate compression and expansion zones, a series of waves similar as produced by a vessel's bow when forced through water. These would be great or small, acording to the speed and angular inclination of the plane and their number determined by its width. But for the elastic momentum they could not be formed.

One may see from this how difficult it would be to work out any mathematical rule for the position of the center of pressure on flat planes that should comprehend any extension, angle and gliding speed. Even a law of comparison such as determined experimentally by Froude for design of vessels would be futile, and for the rest unwieldy and superfluous. In the first place, at great angular inclination, the rear part by co-operating with the front in simultaneously pressing on and confining the air causes the disruptive point (L) to lie near the center of figure; in the second, with decreased angle, as the rear part is thrown out of action by the air overleaping its neutral point after collision with the front, it loses its influences as a co-operative factor and the elastic limit of the air is exceeded so much sooner; until, thirdly, at very small angles (under 3°) the air is pressed on so gently and so slowly displaced that only minute ripplets are formed and the air responds practically as though solid from front to rear.

It becomes instantly evident that flat planes, even very broad, are very inefficient; that to prevent an induced negative, a curved form is the best. The curve not alone by confining the air longer displaces the disruptive point further back—enables the rear part to co-operate and add to the extension—but it also at the same time prevents air if it does overleap the neutral point from causing a negative reaction on the rear surface; that is, if the rear part is flexible and adapts itself to changing actions of the air. Here we may observe another indispensible function for elasticity in the wing structure, in that it always causes the rear part to take part in the pressure and prevent the initial breakdown of the air—add to the "extension" under all conditions so as to prolong the elastic (time) limit of the air.

The foregoing pertains to a "progressing" (attacking) surface, but holds equally for one that is attacked or has a "receding" advance. It should, however, not take any argument to prove that in the case of a receding surface the elastic limit is increased and possibility of fluid disruption lessened. The arrow s2, Fig. 6, suggests the direction taken by a receding surface as contrasted with that of a progressing, denoted by the arrow s. Thus one may understand why it takes so little more power for an aeroplane to ascend than it does to maintain it along a horizontal course. The reason is simply that the air responds so much more solidly when meeting something that yields to it (even upward against gravity) instead of abruptly deflecting and breaking it up. Naturally the required curvature becomes less the more receding or softer the obstruction which the air meets, so it may be readily understood why the under surface of a bird wing is under usual conditions but very slightly curved.

The following points may be regarded established by the foregoing, and find their check in experimental results and facts of observation: (1) the smaller the angle the more "solid" and less wasteful of energy the aerial reaction; (2) air strained and unstrained on meeting a receding surface maintains its solidity longer and does more work on the surface and less on itself; (on a progressing surface it can do no work except upon itself); (3) under usual conditions it may be overstrained and flow away or be elastically deflected when impinging on a receding surface, but it is within limits, the less the more the surface recedes; (4) work which it may do on itself is in any case at its own expense on a surface which recedes. Air flowing against a windmill, the sail of a vessel in motion, etc., acts on a receding surface and does work. Similarly when it strikes a bird wing, it impels the bird forward as well as providing a static sustaining force by its impact. Hence, when such drive is active in bird flight (which it normally is), the dynamically conservative reaction of compression of the rear surface and largely also the induced reaction on the top surface vanishes; the under surface of the wing assumes a slightly curved form, which curvature varies to some extent according to the force and direction of impinging air. This slight curvature furthermore has the important function of displacing the center of pressure sufficiently to the rear so that the rear flexible portion may assert itself in what we shall see is a selective action.

Finally it may be observed that this "supplementary" principle accounting for both a support reaction and impulsion is not something that should be essentially new to science. It is merely an old principle in a new light by elaboration from fundamental principles of motion and force. It shows how birds may glide in air with a minimum rate of fall. Any aeroplane, even the crudest type, when volplaning to the ground illustrates the principle. If it fell in air that rose as fast as it dropped, it would soar. The same was demonstrated more than twenty years ago by Otto Lielienthal, who launched himself in the air on a glider of his own construction from the top of a hill in the face of a lively breeze. As the air ascended fast enough, he often sailed horizontally and was even at times elevated above his starting point by sudden gusts. To him, accordingly, belongs the distinction of being the first man to soar by artificial means like a bird, even though the duration was exceedingly short and his flight very uncertain. For this is the fundamental principle of soaring flight—ascending air and impulses. Lielienthal's gliding experiments furnish in a crude way an example of transfer of atmospheric energy for the impulsion and sustenance of heavier-than-air objects; all air coming in contact with the gliding surfaces giving these a swift glancing blow and impressing thereon some of their force. The only difference between this case and that of a bird is that the latter glides at a far more acute angle of fall, therefore does not break up the air to any great extent but merely dampen its forces by absorption in the most gentle manner. Owing to the qualities of its wings it furthermore does not matter whether ascending air is mixed with equal amounts of descending, whether temporary or constant, whether elastic-solid or fluid—the impinging air units according to their force and direction form their own most suitable angles for transferring a maximum of their contained energy to impel the bird forward and sustain it.

3. The strain of the air's reaction in resisting the bird's weight can never rise to a point greater than the weight; only two things can affect a variation thereof, viz., the bird's inertia and momentum, the latter only when translated into centrifugal force. But these forces can only act momentarily to vary the strain; as when we ascend or descend in an elevator we do not press with our weight more or less on the floor than when the elevator is still, except at the commencement of the ascent or descent. A bird rising steadily in the air, or falling, or sailing in a horizontal plane with constant speed, accordingly acts on the air with the same force. Addition or subtraction of positional energy does not in itself vary the reaction of sustentation, in other words; but in overcoming inertia opposition of the bird at the commencement of a rise, the strain must be increased; and, vice versa, in case of drop, decreased. This opposition is theoretically infinite in an infinitely short time; i. e. it takes time to start the bird in motion upward or forward or add an increment to a velocity it may already have in these directions. The nature of the forces in the air which may add increments to its positional and kinetic energies are often of a sudden type and short duration. They consist of "bumps" on the stream lines high in the air and more or less violent fluid movements nearer the surface. Whether more or less violent, sudden or protracted, they are capable of adding energy to the bird system, if favorably directed; but in view of the inertia of the bird and the characteristics of the air, it is all a question of **time**—long or short—how much or how little energy they can transmit. This time depends for its duration on the characteristic qualities of the surfaces exposed to their action. The bird is represented by its wings in transactions with the atmosphere, and if its wings were rigid and rigidly connected to its body, a sudden impulse striking them would be resisted with all the force of the inertia of the bird in the case. Consequently, before much of the inert opposition could be overcome, the air would have been broken up or deflected, and its force rendered unavailable in furthering the motion of the bird. Here is where characteristic qualities are necessary in order to supplement the constant recession of the wings—make them more instantly responsive. The qualities to which reference is had are two in number—**elasticity** and **lightness.** The former allows the wings to yield with increasing resistance to a sudden impulse, compels them to follow it up by a spring-like return; in short, causes a protraction of the period in which the forces may act—gives them a better chance—something the inertia of the bird would otherwise hinder or cut very short. (Comp. Case II, Chapter IV). The latter (lightness) minimizes inertia opposition of the wings themselves so that they become more instantly responsive to aerial impulses and in combination with elasticity causes such a stretching out of the time of action that the inertia of the bird is overcome in a shorter time than would otherwise be the case. In fine, these qualities in wings provide a soft, cushioned response on their part to aerial influences—make the suddenness of the effective aerial impulses less sudden and tap them of a maximum of their contained energy in the available time. If the impulse is of long duration, these qualities cause the least possible dissipation of energy at the start—effect a quicker response of the whole system. But the moment the initial (inert) opposition is overcome they of course lose their significance, since then the whole system has a proper receding velocity and may benefit from a continuance of the impulse without their intervention. These qualities it will thus be observed furnish, in effect, a necessary steadying element between bird and atmosphere—bridge

their difference—and make these systems harmonize so that transfer of momenta from air to bird takes place with a maximum effect, and all impulses, large or small, of short duration or long, benefit its system to the utmost. The science of flight is in its swaddling clothes yet, and for this reason a matter that should be as obvious as this is reiterated whenever opportunity presents.

This must suffice for demonstrating the elementary principles underlying soaring flight. In their light, it should be a matter of no great difficulty to read and interpret things more in detail in connection with this phenomenon. The more significant points to keep in mind are that, on the one hand, transfer of energy from atmosphere to bird requires a receding surface so that impinging impulses may act to move the bird in the required direction; that no aerial mass striking such surface can affect it aversely since incident rebound or break-up is with a receding angle at the expense of the air not of the bird; but that, on the other hand, as the wings do not rest long on any point and cannot benefit much from impinging air if rebound of such air were permitted, **quality** in the wings akin to the atmosphere itself is of the utmost advantage, as well as proper shape and dimensions.

One point not touched on but which is of some importance is this: that in view of the near solidity by which the air acts on such elastic surfaces, the propulsive and sustaining effect resulting is proportional to the square of the surface dimensions which the air meets and acts on. Compare in reference two typical soaring birds, as herring gull and albatross. The latter, according to Von Lendenfeld, weighs 12,000 grams and has 67 sq. Mm. surface to each 1 gr. of weight; the gull weighs 1,035 grams and has 230 Mm. surface to each gr. of weight. If the albatross had as much surface as the gull in proportion to weight, it would have some 27,600 Cm.^{2} instead of the 8,000 it actually has. The albatross is yet notoriously the better soarer of the two! This at once places the supplementary principle on par with the fundamental, shows that the laws of reactions in one case harmonize with those in the other—a gratifying result, but must be understood to hold only in combination with those qualities in the surfaces which render the bird mechanically an integral part of the atmosphere, and susceptible to its actions.

V. THE MECHANICS OF SOARING FLIGHT

According to our principles, the subject concerning specific mechanisms, qualities and actions of bird wings in turning to useful account the energies of the atmosphere must be based as much on study of the atmosphere as of the wings, since the latter must conform to the former and knowledge of the atmosphere and its laws predicate the mechanism, anatomy, quality and behavior of the bird and its wings.

It is purposed to show that ability to soar is overwhelmingly due to inherent, automatic principles of response, and but in small part due to instinctive or consciously directed maneuvers on the part of the bird. It obtains assistance almost under any conditons from moving air and may turn and go anywhere, unconsciously relying on the soulless automata of its wonderful organs which, as a rule, require no guidance from either lower reflexes or higher psychic centers to act for its best interests.

It is well to remark that the purpose of birds is to hunt food and but to a minor extent is soaring in itself an object in their existence; therefore, they often go counter to the principle of utilizing atmospheric impulses to the utmost in their flight evolutions. For example, it would frequently occur that a gull if it permitted itself to become influenced too much by available atmospheric power, would soon be too high in the air to profit by opportunities afforded those holding a lower position; and for this reason it often foregoes the advantage of atmospheric power when for moments there is plenty and spends considerable muscular power when conditions are negative to hold positions in the flock most favorable to its quest. But here we may largely ignore this and assume what obviously is not true under all circumstances, that birds endeavor to profit to the utmost by atmospheric power, basing the discourse on this assumption.

On the basis that bird wings are adapted for responsive reactions according to atmospheric laws and behavior, the problem in hand quite naturally groups itself under two general heads, viz., utilization of: (1) atmospheric movements having solely a positive tendency (i. e., upward and unmixed with down-moving air) and (2) movements fluctuating in direction on the whole as much down as up. The first requires merely the proper conditions, outlined in the two last preceding chapters, the second requires selective action as well to be of any use as a drive.

1. **Non-Selective Action.—(a) Due to Constant Rise of Air, Fluid and "Solid."** The air movements concerned were described in Chapter II., and consist of rising air due to the action of heat and air deflected upward in winds encountering rising ground and obstacles. The action explains itself, in that position is maintained though the bird falls with reference to the air. It requires some instinctive judgment of the bird based on feeling in order that it may either circle within the confines of rising masses or sail along above ridges and rising ground against which the wind blows and is elevated. Above rising ground, in the higher reaches, the stream-lines of the air-flow become more and more "solid" and horizontal; therefore, if the angle of fall a bird must maintain to conserve its necessary soaring speed is, say 2 degrees, this amount of deviation of the stream-lines marks the limit of height to which it may ascend and soar by such influence, unless its drive is supplemented by other atmospheric forces at the same time.

(b) **"Radiated" Energy.** The author saw in 1905 three condors soaring at a tremendous altitude, probably three miles from the ground, as they appeared as mere specks. Place of observation, in the central part of the Panama Canal Zone. A light trade wind was blowing, but it was impossible to assume that any part of this wind was deflected in a fluid way to that altitude, nor was it evident that there could be any **general** ascending trend to the air, or that over the rugged tree-clad country of hills and dales the deviation of stream-lines reached that far; moreover it was not evident that they lost or gained position as they glided along. I followed them with my eyes until they disappeared southward. Not for an instant did they flap their wings. Humbolt claims that this bird soars to an altitude of at least 20,000 feet above the sea. From the Cave of Autisana, Andes Mountains, which is at an elevation of 12,958 feet above the Pacific Ocean, he observed a condor rise to a still greater height of 6,876 feet. Other authorities state that it reaches a height of six miles above the sea level, which is in the region of the cirrus clouds, about six times higher than the ordinary clouds. It would be absurd to think that it spent muscular power to attain such heights; it merely goes that high because it adds to its comfort and costs no effort.

(To elevate 20 pounds to a height of six miles means the expenditure of 623,720 foot-pounds energy, only considering the gravity resistance!)

Now, ascending air currents may reach such altitudes in tropical countries, but their existence is hardly in itself a sufficient hypothesis to account for the constant ability of these birds to ascend and maintain themselves in the air indefinitely like balloons. Here is evidently where "radiated" energy comes in to supplant the force of "aspiration" invoked as a hypothesis by French writers to account for this phenomenon. This form of atmospheric energy was demonstrated to exist; see Chapter II, Section 3, to which reference is had. It is in the form of a progression upward of infinitely numerous elastic air waves or impulses and could be called the "pressure of sound," though the term "sound" carries the notion of audible frequency whereas these waves are as a rule of an infra-low pitch. The conditions for the reception and effective dampening of such impulses have been indicated. As they all impinge on the under surface, there is no need of selective action and quality proper has comparatively little to do with their utilization except as it makes a receptive angle possible. Now let it be understood that ordinary sound waves of the shrill whistle type, etc., have exceedingly little potency for work. We may reckon the impact force of such to be of almost infinitesimal value. That nevertheless they do count in aggregates of billions when spread over a length of time and in combination with millions of others of greater amplitude, should be evident. On ordinary surfaces, sound waves are reflected as an echo or refracted (going through at various angles) and do no work of the kind here demanded. Work requires that they be dampened or absorbed in furthering the motion of what they impinge on. Stiff, immovable surfaces merely serve to change their direction. To dampen their energy and prevent reflection with as much force as impinging, there is required that they strike something that recedes, and recedes more owing to their influence—something, in fine, that yields to their onslaught and on which they can impress a modicum of their energy in furthering the recession. This condition is fulfilled in a wing surface such as the condor or other bird presents, which glides at great speed with a receding (receptive) angle.

Not all the energy of the impulses intercepted by bird wings is absorbed in this way. There is every reason to assume that there is an echo, though always a dampened one. As to refraction, it is probably exceedingly slight, if any, considering the nature of the surfaces. For total absorption, there is required that the wings travel much faster and with a more obtuse angle of recession than they do. The conditions for total absorption are, however, possibly met with at the extreme rear edge which owing to extreme thinness and elasticity may recede sufficiently to negative a reflection of such part of a wave as impinges thereon.

As to whether this form of energy is sufficient as a drive for such a bird as the condor, not alone to maintain it at soaring speed in the horizontal plane **but more,** this involves quantitative estimates that with the available data must prove inconclusive. The resistances to this bird's progression at soaring speeds below the critical, when more precisely determined, would furnish the lacking data for determining the necessary driving force. All that may be said for sure is that the air resistances are small, probably not exceeding one-fourth foot-pound second in the case of this great bird. If so, this would not seem beyond the capacity of this form of radiant energy to supply. For, take notice that a portion of the total energy of wind movements at the earth's surface, and probably as much as one-fourth of this total, is transformed into elastic ascending pulses and accounts largely for the retardation and stoppage of the winds. While much of the energy of these pulses is debased into heating the air through which they travel, yet they should arrive at great heights with considerable remaining potentiality. One may also note that this bird spreads considerable surface for the reception of such impulses, the tail being included. Moreover, in direct ratio as the bird ascends the more numerous become the **effective** impulses impinging on its wings, since this depends on the incidence of these latter with reference to the ground from which the impulses emanate. Thus at an elevation of three miles the condor may very well benefit from the energy "radiated" from every spot of a circular territory of six miles radius, whereas at a lower elevation the effective impulses would be fewer in proportion though somewhat more powerful individually.

This form of drive is of course always present in the air over ground over which winds blow and may be added to others of more tangible form. It also goes without saying that these ascending waves, whether absorbed or not, add their quota on impact to the sustentation, according to the principles hereinbefore stated.

2. **Selective Action.** Fluid movements near the surface and incident elastic-solid movements at some height above, as demonstrated in Chapter II., have more or less vertical components of direction—as a rule as much down as up. In order that profit may be had from these, so that the negative of downward flow shall not interfere with or equal the positive effects of upward, there is needed selective action—Lord Kelvin's "Sorting Demon." This demon is not hard to find and his simplicity is great when stripped of a mysterious exterior. His whole being is wrapped up in gravity itself, and it will be my endeavor, after a few preliminaries, to uncover and expose to view as much of his inner anatomy as possible.

The elasticity of bird wings and their working mechanism is complex and difficult to describe by mere words. One must handle a live bird and examine its wings to understand all there is to it, as well dissect the bird when dead. This elasticity is as extreme as can well be imagined and comprises three main systems: The fore-and-aft, the longitudinal and the lateral.

(1) The **fore-and-aft** concerns the adaptability of the wings for automatic changes in angular travel. Its functioning parts are four:

(a) The flexibility of the feathers which lie side by side overlappingly in the fore and aft direction.

(b) The pivoted attachment of the feathers to the bones at butt ends and a strip of elastic tissue binding them to the bones from underneath. The quills of the feathers ar relatively stiff except at the posterior ends, but the barbs extending from them are exceedingly flexible. The main feathers are covered by smaller and the wing structure built up so that perfect surfaces of smooth exterior and proper outline are formed. The feathers slide on each other fan-like so that any section is quite independent of adjoining in yielding to pressures. Both their curved form and flexible attachment at butt ends combine to make them more resistant to pressures from below than from above.

(c) The wing bones form the foundation of the wing structures. They are attached to the skeleton of the body by peculiar ball-and-socket joints, differing in minor particulars among different species. These joints allow a wide-limited swing in all directions as well as a wrist-like rotation. This rotation alone concerns the fore-and-aft adaptability and is restricted by elastic tendons and tissue. The center line of the pressure counteracting the weight falls some distance behind the pivot point, tending to rotate the surfaces upward on their longitudinal axis. This tendency is balanced by the elastic connections referred to. Variations in the pressure affecting the whole wing therefore cause instant variation of the angular travel of the wing over and besides that of the independent sections described under (a) and (b).

(d) To this must be added as an "elastic" element the moment of inertia of the bird on its transverse axis. The fore-and-aft direction of the bird's body in the vertical plane is largely maintained in the proper direction automatically in virtue of the **lateral elasticity**, [(3) below] though as well controlled by reflexes and voluntary muscular movements. The object of the bird is to advance with as little resistance as possible and so it is not enough that alone the wings should adapt themselves to follow the component direction of the aerial stream-lines, its body must conform thereto too as far as practicable so as to present at all times the least resisting aspect to the air.

(2) **Longitudinal Elasticity.** This refers to the flexibility of the wings along their longitudinal extension.

(a) The bones are slightly arched, as are the feathers extending in this direction toward the tips. They are quite flexible but yielding, by virtue of form, far more readily to pressures from above than below.

(b) The wings swing on their pivots up and down. This swing is restricted in the upward direction by elastic ligaments, skin-cover, tendons and muscular tissue. Though movable by muscular power, yet, in virtue of these elastic connecting parts, no muscular energy is spent in merely holding the wings in position balanced against the air pressure; the static tension of these connecting parts take care of that and at the same time form no hindrance to muscular movements. There are no similar elements resisting the down-swing, so only upward impulses can impress themselves.

(3) **Lateral Elasticity.** This has reference to elastic and will-controlled restrictions against the wings' advancing forward or backward, the principle by which changes of the relative positions of the center of pressure and center of gravity are affected, the tail being a secondary functioning part to this end. (The tail has but minor concern in the selective action to be described and its office must be looked for more truly in connection with a semi-automatic system of equilibrium. As it is not intended to include a description of this system herein, little attention will be paid to it.)

There is one extremely important point to be borne in mind as to the functions of these elastic elements, and that is: as the weight of the bird induces a strain in the air balancing it, this strain again is reflected in an equal and opposite stress in the wings—to-wit, all the functioning parts of the latter are bent or stretched to a degree of stress or tension corresponding to the aerial strain. As the strain varies, so does the stress; or vice versa, these terms being interchangeable according to whether looked upon as action or reaction in these respective cases. There is a double, triple, quintuple and even septuple connecting series of elastic elements brought into play in this system which in resultant capacity for responsiveness well nigh equals the elasticity of the air itself. More would be impossible. As these elements are as extremely elastic as they can be, their deflection when subjected to pressure is also as extreme as possible within permissible limits. A wing and its component parts must be unbent far indeed from normal stressed condition before the point of complete relaxation is reached—something instantly apparent on examining a wing and its connecting parts merely by touch.

The gravity constant holds these elements in normal stress and tension as the bird glides in the air, but owing to the bird's inertia the stress and tension vary according to the vertical movements of the air. Thus when the supporting pressure is suddenly diminished below normal by reason of the wings' entering falling air, it takes some time before normal reaction is recovered by the resulting drop of the bird. The elasticity of the system here comes in and not alone prevents the pressure from vanishing in such case but diminishes the drop by a practically instantaneous responsiveness. If the pressure suddenly increases, due to rising air, it likewise is instant in response to diminish the suddenness and prolong the action of the force until the inertia opposition is overcome. This system of elasticity in other words adds a necessary steadying element between the gravity potential and the inertia of the bird so as to even out and make the best possible use of all positive impulses and, as will be better explained, render the negative innocuous.

In the figures used to illustrate the action more plainly—8, 9 and 10—arrows are employed to denote the "component" direction of impinging air. The wing sections shown are considered to move horizontally (from R to F) or with reference to the air in direction opposite the arrows; thus, even if this air has a plumb up or down direction in space it is evident that relative to the swift-gliding wing it becomes inclined and must be so pictured (Comp., Chapter V. on angle of recession). The horizontal velocity of the wing and vertical (component) velocity of the air determines in all cases the inclination, which however does not vary between very wide limits. This point is well illustrated when we look at a crow or gull as it flaps its wings in gliding flight. One observes no noticeable difference in angular travel whether the wings move up or down. Yet, one must know perfectly well that there is a difference, since otherwise the up-stroke would be the negative of the downstroke, instead of as it is, and should be, neutral. On account of the swift glide, the difference is small, and that is what makes a casual observation inconclusive. So, likewise, if we consider the air to have relative movements up or down with reference to horizontally gliding wings, the angular deviations they produce are on the whole quite unnoticeable while they may be, even so, of far more potent influence for impulsion than muscular strokes (as, e. g., shown when a bird is tossed high in the air at a single bound by an air upheaval).

All figures employed in the analysis following are diagrammatical and in exaggerated form and proportions to make the ideas they are designed to convey as obvious as possible.

For the sake of convenience, the subject is divided under three heads—"a," "b" and "c"—respectively, concerning the influence of relatively small, medium and large-sized air masses as they by moving up or down affect the bird-system. To be sure, no definite size can be assigned to air movements of this type, whether positive or negative; they grade by insensible stages from such as may be measured by fractions of an inch to such as extend for hundreds of feet. As on the ocean we observe in a storm large waves of various magnitudes and superposed on these smaller ones of different sizes, and on the latter again the tiniest ripples, so with aerial movements in this reference. Yet a classification not altogether arbitrary may be had by naming such **small** as affect only a minor portion of a wing surface at a given time; those **medium-sized** as affect momentarily a greater portion, or for an instant the whole, and those **large** as cause the whole system to be immersed an appreciable length of time within their mass. While reviewing the influence of these separately, it should be understood beforehand, that as they concern movements, in interlaced forms, of the air itself, all three may be simultaneously effective in transmitting their momenta to the system coming within their confines.

"a" **The Positive Function of Fore-and-Aft Adaptability.** Let the curved forms shown in Figs. 7, 8, 9 and 10 represent outline cross-section of a bird wing, say on x——x, Fig. 11, the dotted line F——R denoting horizontal line of travel. Fig. 7 represents the form of this section when the wing is **not** in action, the surface in consequence being totally relaxed. The arrows indicate the **relative** directions of the impinging air, which may be horizontal and totally opposed (Fig. 8), componently upward and opposed (Fig. 9), and componently downward and opposed (Fig. 10). Fig. 8 shows the wing **in action** in calm air, or rather air moving horizontally without vertical deviations. The potential difference in the air strain caused by the pressure accounts in this case for the change in shape as compared to that shown in Fig. 7, the under flexible surface being shown flattened out, and the flexible parts considered in tension equal to the pressure acting, which distributed over the total supporting surface equals the weight and for any section equals some part of the weight.

Figs. 9 and 10, respectively, show the forms assumed by the wing section when cleaving moving air having proper directions upward and downward. In the first case (Fig. 9), the pressure rises above the normal for the section, whence the feathers yield elastically at their rear margin and especially at their junction to the wing bones. As results from this, it will be understood at a glance, an added impulse is given to the system at this point, the component directions of which are upward (lifting) and forward (accelerating). In the second case (Fig. 10), the section cleaves a point of falling air, in consequence of which the strain becomes **partly** relaxed. "Partly" is used pointedly as the horizontal speed of the wing connected with the weight it supports constantly holds the surfaces in a **normal** state of tension, and for the small-sized air movements with the action of which we are now occupied to cause a total relaxation or more (negatively depressing the wing section) would be impossible under the impact conditions obtaining. Such minor air masses have not vertical speeds of bullets nor are they as a rule independent of larger movements accompanying. The extent of the unbending they cause at local points of a wing surface should be measured by fractions of an inch less than one-eighth rather than more. Therefore, and since the deflection caused by the load is incomparably greater, instead of a negative (downward) pressure resulting, the effect of such small negatively directed air is **neutral** so far as the section affected is concerned, or merely to lessen the resultant positive so far as concerns the whole wing. Accordingly, as neutralizing but a small portion of the total, the effect of such minor regative movement subtracts correspondingly little from the total reaction and must, moreover, be judged, in view of the turbulency of the atmosphere, to be simultaneously at other points, or promptly afterwards at the same point, made good by ascending air striking the surface in rapid succession as the wing sweeps on tarrying at no point long.

What is important to note is that we have here a decidedly one-sided transfer of momenta, a selective action of the simplest type whereby forces acting in the aggregate as much and as often up as down are only permitted to impress themselves—do work—when acting upward. Or, differently stated, the force of air directed upward on striking the wing surface acts against an absorbent resistance, consequently **must do work,** while air moving downward, instead of affecting the surface by impact, merely lessens the supporting pressure (which has as instant result that the surface unbends sufficiently to evade its action), consequently such down-moving air, meeting no resistance, **can do no work.** It is well to recall in this connection that aerial forces (as any other force in the universe) to be able to do work must act against a resistance which is yielding; for if such forces act against a rigid obstruction they are impotent for moving such obstruction and can at best only turn upon, and break up or deflect the masses in which contained. In this simple axiomatic proposition, old as it is in mechanics, the key is found for unlocking the mystery of a phase of soaring flight which must heretofore have eluded scientific investigators. From it the importance of elasticity in wing structures may be apprehended at a glance when taken in connection with the known condition of the atmosphere. It matters not whether we regard the quivering elastic movements of air hereinbefore described, "bumps" or streamlines, etc., or local fluid movements up and down; whether the surface affected is great or small, the result is the same: the flexible wing, bent and greatly deflected by the aerial strain due to the load they support, sweeps through and receives an accelerating boost from all that are positively directed and nicely evades the influence of those that are negative. Per contra, a stiff, unyielding surface advancing with a negative angle cannot well be conceived to benefit from such forces; rather should we assume they form a hindrance to its progress, causing jars, destructive vibrations and stresses. Numerous instances are of record showing that larger and more powerful movements have bursted the strongest artificial surfaces by action either from above or below and have in several cases, without breaking the wings, hurled the occupants with catapult force a clear 20 feet from their seats in an aeroplane traveling high in the air. From this an idea may be gathered of the potency for work of aerial forces, how important that they should do the right kind of work or no work at all.

"b" **The Positive Function of Fore-and-Aft Adaptability of the Whole Wing in Connection With Longitudinal Elasticity.** We may describe this as: Automatically to control the direction of the cleaving edge, moderate the pressure and abstract helping effects from medium-sized masses in vertical motion.

The mechanism for controlling the up and down swing and rotation of the wings on their longitudinal axis may be rendered by a diagram. The one given for this purpose in Fig. 12 shows not what is actually found on dissection of a bird, but merely essentials connected with this explanation. On dissection we meet a more complex state of affairs, since birds must have power to control all things aside from automatic action—fold, flex and extend the surfaces, etc.—and if one thing can be adapted to perform two or more separate functions, we may be sure to find it so worked out in their anatomy. No greater inventor than Nature for simplifying everything to the utmost and yet make things appear complex and hard to unravel. In this figure, A represents the elastic elements holding the wings statically in position, and B similar elements restricting the **angular inclination** of the wings. The latter (B) acts in conjunction with, and supplements the function of the elasticity proper of the individual section of the surfaces, viz., to regulate the inclination of the wings according to aerial movements. It also acts jointly with A and is in actuality not to be distinguished from it. The point is that they are elastic and in flight stretched into tension sufficient to counteract the leverage due to the air strain acting on the wings, and that they must adapt themselves to this strain. As the strain fluctuates, so must their tension.

Such being the case, they act mechanically as springs and jointly serve to moderate the fluctuations of the pressure: the one by causing the whole wing to yield upward or downward; the other, by inclining the surfaces more or less cutting off excessive pressure and guide it into the proper component direction for best use. As springs they have relation to a bird somewhat as the springs of an automobile have to its body. And as the minor shocks due to the smaller inequalities of the road surface are neutralized by its rubber tires, and as the minor "inequalities" of the air (as shown under "a") are immediately taken care of by the flexible sections; so, as the springs of the automobile neutralize the effect of larger irregularities of the road surface, do these elements stand between the inert body of the bird and its supporting surfaces and smooth out the effects of encounter with larger irregularities of the air.

They have in addition, however, a more positive function than such as pertains to the analogous case cited, and this for the reason that the "inequalities" in the air are of the **vis viva** kind (active, can do work) whereas the inequalities of the road surface are purely of the **vis inertia** kind (passively resisting, but incapable of work). Therefore, and using the same arguments as under "a" above in demonstrating the positive function of the fore-and-aft elasticity of the individual sections, they enable the wings to take advantage of the abundant energy of atmospheric movements, the system receiving an accelerating boost from upwardly directed air while evading the effect of down-moving. It should be unnecessary to elaborate further on this point itself, as, if the subject-matter under "a" has been understood, the parallel case here brought to view should be equally clear. Only it requires notice that here we are concerned with larger upheavals and depressions of air masses which affect the whole or the greater portion of the surfaces momentarily, instead of minor sections of same, and that they have, accordingly, a far greater significance for work of the kind demanded.

Added to the function of the element **A** should be the longitudinal elasticity of the wing bones and tip feathers. This of course supplements **A** and aids to the same end; namely, as the wings are thereby maintained in a state of whip-like stress when sustaining the load, to make them more instantly responsive to impulses received, whether for evasion when negative or for reception when positively directed. To the function of **B** may similarly be added the torsional elasticity of the wing bones.

It may be noted that these reactions of the wings in response to actions of the air are contingent solely on the inertia of the bird as resisting element, while its momentum determines the extent of the responsive movements. The gravitational action determines indeed that the action shall be selective but not that the wings shall move in response to aerial movements, the wing motions having reference alone to the body supported. Hence may be derived the rule that the average range of the wing deflections caused by aerial movements are, **caeteris paribus,** (i) directly proportional to the square of the surface dimensions in any series of characteristic speed configurations, (ii) directly proportional to the weight supported by the wings, and (iii) inversely proportional to the square of the speed of translation. From which may be drawn some interesting conclusions concerning the extension of the principle, showing that in some proportion as weight is increased (and other indispensable factors duly proportioned) the effectiveness of selective action increases.

Also it may be remarked, though it should be unnecessary, that the form of the wings—their convex top and concave under surface—quite apart from their quality has some importance in not permitting the effect of negative forces to equal the positive. In this connection may be mentioned that some variations in the structure of the organs of soaring birds obtain which receive their explanation when mode of living and prevailing aerial conditions where they live are taken in account. Thus the giant albatross has wings differing quite considerable from those of the condor, though their weight is about the same. These are the soaring birds **par excellence** in nature and it would not be evident why their wings should differ unless conditions in their mode of living so prescribed. The habitat of the albatross is over the oceans swept by trade winds and it keeps close to the surface. Here the air is constantly "splashed" upward by impact with the waves. As mentioned before, this bird has a hollow space underneath, close behind the front edge of its wings. In this hollow is formed an air cushion at normal pressure, constantly in rotation and slowly replaced by "new" air in the onward glide. The exceedingly numerous elastic impulses which strike the surfaces from below have a very potent influence in virtue of this cushion for impelling the bird forward. Without it, as is evident, they could not so well be captured and caused to impress themselves by prolonged action in the right direction. Fluid movements are too slow to have any effect on this cushion, otherwise than would be the case were it absent. Since it would be impossible to endow this front part where the concavity is situated with that "quality" on which we have been compelled to lay so much stress, Nature here accomplishes in a measure the same thing indirectly in a very simple manner. This may be termed **indirect elasticity,** due to form, and has perhaps more importance for non-selective than selective action. As involving an inharmonious speed configuration, it has however certain disadvantages and these can only be overbalanced by advantages arising from such air conditions as prevail where the albatross confines himself. The condor, on the other hand, flies high and over land in mountainous regions where air conditions are different, thus on the whole is best served by the specialized organs it is provided with.

To check the results so far given by visual observations is possible for anyone who is interested and will take the trouble. For this purpose may be especially recommended the large buzzard inhabiting the airs around the Florida Keys and West Indies. Fig 11 is drawn to indicate, in perspective, the outline of its wings in action as seen from the rear. The rowing feathers are seen distended apart and bent upward by the air pressure. By noting the action of these feathers, when the bird soars close, as they mechanically adapt themselves to fluctuations of the pressure caused by air movements and taking in account therewith the action of the whole wing and the flight of the bird, one will soon see the theory here advanced well sustained. By looking over a window sill or other convenient level surface, it will be noted that the under plane surface approximately coincides with such level, though on the average the trailing edge will be found slightly raised. On the assumption that the line of progression of the bird with reference to component stream-lines of the air coincides, on an average, with the longitudinal axis of its body, one may obtain further basis for visual observations covering these matters. The tip feathers of the wings of the buzzard when soaring may be seen to bend both upward and forward, denoting that they do their share in both pulling and sustaining the bird. These feathers never unbend to the point of complete relaxation, though independent of muscular action, they have in connection with the whole surface a considerable elastic swing up and down, as is very evident when one watches. However, one must not be mislead by any description herein given into assuming these movements to be at once very obvious and noticeable during the fleeting moments and generally unfavorable conditions prevailing for making such observations. The contrary is the rule, but by patience and practice, good cases can be made out with positive results. One must ever remember, as has been insisted on before, that these birds maintain considerable air speed, that motions of the elastic elements in consequence become small, that minor air movements are generally accompanied by greater, and moreover, that the inertia of the bird is soon overcome and the whole system moves (up or down) in consequence of fluctuating pressures.

(c) **The Positive Influence of Gravity in Selective Action.** Without the action of gravitation—or, say, the bird were, like a fish or air-ship, of the same density as the medium in which it moved—the forces of the atmosphere would be impotent for work and soaring flight an impossibility. As an elastic invisible string it constantly pulls the bird down and is only prevented from doing so by the static resistance of the air, as has been shown in Chapters III and V.

Its one-sided action would at once suggest that it could of itself perform positive functions similar to the elastic elements described which operate in connection with inertia as fulcrum. This is truly so. Its selective function shows itself in connection with the temporary larger upheavals and declines of air masses in which perforce a gliding bird must remain appreciable lengths of time. Observation conclusively proves that birds are not injuriously affected by the action of these; on the contrary that they are benefitted. The question is as to the mechanical details and aspects of the problem.

Without preliminaries, I think the case may be roughly resembled to that of a rubber ball dropped from a height **A** to the floor. The ball on rebound does not ascend to the height from which it dropped, **A**, but to a point lower, **B**. Whether dropped in falling, still or ascending air makes little difference in this respect; it always bounds back to a point below **A**. If, however, we conceive it dropped in descending air and allowed to rebound in ascending the case would be different. It would then on rebound ascend to a height greater than **B**, and even than **A**, depending upon the amount of lessened resistance or aid thus afforded by the moving air. In other words, were it given a sufficient impulse from without in addition to the gravitional action and the elastic forces of compression and deformation each time on impact with the floor, it would not lose motion but would bob on as long as the impulses lasted. Similarly with a bird moving from one mass of rising air to another through falling; the transfer is made without sensible loss to its system. The conditions making it possible for the bird to thus benefit are that the kinetic energy generated in its fall in falling air be translated with a minimum loss into the potential of position in rising air. This can be fulfilled only if the air is at no point overstrained in the translation. It is effected by the bird by a gradual swooping movement, the impact at the bottom of the swoop (if it can be termed "impact," compounded as it is of the incident centrifugal force and weight) being cushioned and moderated at all points of the curve by the elasticity of the component parts of its wings. Gravity, so to say, swings the bird like a pendulum from one rising point to another; and as a pendulum receives an impulse at each swing by the clockwork escapement to keep it going, so the bird gets a gratuitous boost by each air upheaval to keep it moving. The principle is the same in both cases, yet to the onlooker there appears to be little similarity simply because of the great irregularity by which the bird is thus impelled and the fact that it does not swing back and forth but continues onward in an undulating path, perturbed at all points by the influence of smaller irregular movements simultaneously acting. As its wings are designed and able to carry overload, there is no reason why they should overstrain the air in the swooping curve, so long as the curve is graduated within the capacity of the overload factor.

The assertion is not herewith made that a bird benefits positively—adds energy to its system—in crossing the "gap" of falling air, between rising masses; but it may be contended that it covers the ~~distance~~ space separating them under conditions more favorable to the conservation of its energy than if the space were occupied by "neutral" air. The "gap," wide or narrow, has to be crossed and with necessary greater speed in crossing the bird all the sooner comes under the influence of positive air again. Thus a time element enters which is not unimportant, since it signifies that a bird **of necessity** spends a longer time, relatively, in such rising masses than it does in falling and must benefit accordingly. This principle is automatic but may be further extended by wilful or reflex action on the part of the bird. The **modus operandi** then is: A bird may increase or reduce the area of its surfaces and alter their harmonic speed characteristics at the same time, as fundamentals prove; hence, in entering falling air it may at once reduce surface area (close up tail and flex wings, making them shorter and broader and ease their curvature) and glide down at a steeper inclination, and as soon as its centrifugal force commences to act reverse the operation, spread more surface and go at slower speed, thereby prolong the stay in rising air in proportion as in falling air it is shortened.

Now the next time the reader sees a bird soar near the surface, preferably a gull striving to catch up with a fast steamer going against the wind as then it fails of no effort to obtain as much benefit as possible from atmospheric power, he should watch for just this point. He will see that the bird now flexes the wings and closes its fan-like tail, that now they are extended to the utmost, that the bird's progression is not in a straight horizontal plane but undulating. It may be so anxious to catch up that it liberates some muscular energy now and then, but on the whole it will be seen to draw nearer and nearer by air power alone as though the steamer had some magnetic attraction. Observations on this point are however inconclusive and reason pure and simple must be relied upon, since we cannot see the air. For now a bird may be seen to ascend with contracted surfaces, now with distended; and, vice versa, descend with more or less surface exposed. This obtains its explanation from the fact that air in horizontal winds fluctuates in velocity and for certain lengths of space has no vertical component of direction. The bird in entering such faster moving, "neutral" air has its air-speed thereby increased, and this speed would be greater than its soaring-speed and often, maybe, even greater than its critical. It therefore instantly adapts the speed harmonics of its wings to this condition and transfers the resulting excessive kinetic energy to the position reservoir—ascends—using this temporarily stored energy when the squall passes to maintain its soaring speed in the slow-moving air supervening. From this may be figured out exactly what operation best suits it under any condition, and one may tell off-hand with approximate certainty whether the bird now is immersed in falling air, in neutral slow-moving, rising or neutral-fast-moving. But, as said, to undertake to prove things by direct observation were vain.

As this principle in the selective action of the bird system is undoubtedly the most potent of all, it may be worth while to analyse it a little closer. The fundamental proposition is that bird and air form two systems in opposition and balancing each other. The gain of one is a loss to the other. The bird has energy in two forms, kinetic and gravity potential, but leaving aside the former, its gains and losses are reflected in the gravity spring as though it were a barometer. The gains and losses of the aerial system show up in acceleration and retardation of its movements. Two propositions then come up, namely the fall of the bird with reference to the air and its fall with reference to the ground. These are distinct and separate factors, since the bird may fall with reference to the air and yet rise with reference to the ground. Its position with reference to the ground determines its potential energy and the degree of its ascendancy over the air-system at any instant. Now, in order to conserve its momentum, the bird must fall with reference to the air in the aggregate equally much in a given time regardless of whether this air rises or falls. We may name it the "constant fall," as representing the resistance balance to horizontal progression. If it falls with reference to ascending air, it may rise with reference to the ground, depending on proper velocity differences. But if it falls in falling air, the sum of the vertical velocity differences gives the vertical velocity of fall of the bird with reference to the ground and at the same time shows the rate of its loss of potential energy. Its "constant fall" is a constant loss in this as in any other case, but any fall outside of that while a loss of potential yet remains "within" the bird as an equal gain of its kinetic energy—not a gain to that of the air which is not accelerated unless overstrained. As it means an excess of kinetic energy to the bird system, this excess is, according to our fundamentals, returnable again to the position reservoir whence derived. From this it is at once given that falling air has no negative possibility in itself; it cannot subtract energy from the bird system and cause an addition to the kinetics of its own, except indirectly as it may impose on the bird necessity for increased speed and incident greater resistance loss. Its effect can only be neutral, not negative—something that may at first sight seem paradoxical, yet contravenes no principle of mechanics—as a fact must be so.

Now, in these energy transformations "within" the bird-system the kinetic must go via a curved (centrifugal) path to the potential, as in the swinging of a pendulum, but the curve need not be supposed to be of an abrupt form, or small radius, in view of the constant horizontal progression of the bird. To an observer on the ground a soaring bird advancing against the wind may often appear to drop perpendicularly in such cases, but this is simply a mere appearance and has no reality with reference to the air itself. Similarly he may see such bird elevated straight up in space—another illusion if considered relative to the air itself which moves against the bird.

In studying this principle, one should take in account that this selective action is most potent in the lower atmospheric strata, the air upheavals and declines there being most active; that these movements of the air are necessarily limited both in extent and duration because falling air, or air forced downward, soon encounters the ground, or inert air backed by the ground, and is quickly reversed in direction; furthermore, that unlike a floating log bobbing up and down on the surface of the sea, here we have a horizontally progressing system of a density about 700 times greater than the medium supporting it, which last is what renders the principle possible.

In further proof of this gravity-momentum selectiveness, the same considerations may be applied as were given under "a" and "b" above, viz., to do work a force must act against a resistance that yields and absorbs it. The bird offers no resistance to drop outside of that due to its inertia. It offers no other resistance to elevation either, but the gravity spring intervenes and the forces of the air must do work when "stretching" it. No such absorbent resistance is given when an air-force acts downward, therefore such force cannot be spent by transfer. Even were the wings stiff, non-evasive surfaces permitting resistance to a force acting from above so that such force would accelerate the bird in a component direction downward and forward. this could not subtract energy from the bird system and show up as an addition to the kinetics of the air; quite the reverse, it would be a loss to the air and gain to the bird—only in a way, to be sure, that would be troublesome to the latter.

From this it follows as a synthetic result that the mode of selective action of gravity and momentum is identical in essential respects with that shown for the elastic elements described under **"a"** and **"b"** and merely supplements the latter. (More properly it may be said that **"a"** and **"b"** supplement **"c."**) This is the more evident inasmuch as aerial movements differentiated in no other way than dimensionally were concerned in the three cases; that furthermore, with a little license, it is permissible to qualify gravity and momentum as elastic forces—stretchable potential elements for storage and return of energy—whence the identity is complete.

In closing this chapter, attention is called to the nearly total automatic action of the bird-system (wings and bird) in meeting different aerial conditions so as to extract the utmost benefit from them. In non-selective action this was plainly evident and in selective action perhaps equally so, since it was due, firstly, to the system of elasticity of the wings and, secondly, as this was related to the functions of—(1) gravity, holding the wing-system in constant spring-like tension and constantly impelling the bird forward with a receptive angle, (2) the inertia of the bird and (3) its momentum. All of which involve mechanical elements and forces independently acting and responding for the best interests of the bird in its transactions with the atmosphere. Evidently all it needs to do is to maintain equilibrium; as when sailing a boat all we have to do is to keep it pointed right, the buoyant reaction upholds it and aerial forces drive it.

VII. GLIDING SPEED

With birds soaring in horizontal winds the rule is that their air-speed is greater than the proper velocity of the wind and its component parts. Singling out an example, a buzzard in a wind blowing 10 miles per hour over rough ground, shown to have no **general** deviation upward by observations on smoke issuing from numerous chimneys, advances over the ground, in direction opposite that of the wind, at an average rate of 10 m. p. h.; thus its air-speed is 20 m. p. h., or as two to one compared to the wind whose velocity is related to the ground. The proportions, I am sure, are often as three to one and even greater in many cases, but it is sufficient to indicate as a problem requiring physical explanation that the air-speed of the bird is greater than the air that supports and drives it, and that this holds no matter whether it goes against, with, or obliquely across the wind's direction. How, then, does it come to pass that the atmosphere thus turns upon itself and forces against its own mass a foreign (though mechanically amalgamated) body and gives it a velocity greater than it has in any direction? The "how" has been determined but not the "how much."

Here it may immediately occur that Case 2, Chapter IV, giving examples of exchange of momenta between elastic bodies of unequal mass would find application. The possibility surely is therein indicated that as the masses of the air stand in no proportion of equality to that of the bird, the latter may receive enormous impulses from rather slight movements, consequently that it might be repelled with a velocity far greater than the velocity of the masses with which it has momentary transactions. A similar example is afforded when we spread sand on a plank and give it a blow with a hammer from underneath; the sand is thrown high in the air while the plank does not move perceptibly. An elastic impulse welling upward, or an upheaval of air toward the bird has the solid ground for backing; so in one respect it might be considered as the whole earth versus the bird when the impact force strikes it. And the limit of velocity in this case, as a theoretical proposition, would be almost the velocity of sound imparted to the bird, regardless of the velocity proper of the air masses that strike it. However, this view will not hold water, as no more air can take part in the action than is reacted upon during actual time of contact, and this depends on the horizontal speed of the bird, fore-and-aft dimensions of its surfaces and the penetration of the reaction impulse at sound velocity in the mass concerned. Nevertheless, it is interesting to note that the weight of air that may be elastically affected by reaction in one second's time in the onward sweep of such bird as the giant albatross, weighing 20 pounds, is about 1,200 pounds—or proportional as 60 to 1—quite sufficient to give striking disproportional effects. But though this has some bearing on the problem in hand when searched to the bottom, I think it may be dismissed without further ceremony by considering that as an actual proposition the bird's wings are at all times sandwiched in between layers of the moving masses themselves and its whole system is mechanically speaking an integral part of the atmosphere, consequently cannot become hurled away faster than such moving air, even were it otherwise adapted for response to elastic impulse velocities, something it is not. Notwithstanding this, the principle throws an interesting side light on actual phenomena observed in bird flight; for instance, in a storm one may see gulls around the docks hurled upward with surprising suddenness to considerable heights, sparrows with keen perception select the "hard spots" for bounding through space and gain the roof with comparatively little exertion on windy days. The latter bird no doubt obtains disproportionate effects and this simply by instantly closing up its wings after intermittent clashes with moving masses; but the gull thrown upward as stated is so affected because of the combined force of its momentum and momentum of air having great upward speed. I have never seen any evidence that the upward speed exceeded that of the air in its case unless it used muscular energy for the purpose. The matter has reference to the horizontal speed more than the vertical, and so when looking into angle relations things become more promising.

Here it is immediately given that, abstracting resistances to horizontal progression, or considering the air as "ideal," there is no theoretical limit to the speed the bird may attain, no matter how slow the air that rises and drives it; for this depends on the angular relation of the surfaces to the horizontal and may be conceived small to any extreme. Only it is to be borne in mind that the smaller the angle, the smaller the component force of the bird's weight that drives it, and as air resistances are there and increase with the speed there is soon a limit beyond which the speed cannot be raised in this way. But it should be a puzzling matter only to those who are not acquainted with the analogous principle operative in the case of a tacking sailboat to understand how it is possible for the bird to travel faster than the air which moves it on this principle. It is a matter well known to yachtsmen that racing boats with great sail-spread in very light winds cut through the water faster than the wind blows across their direction (but of course not when running with the wind). The ice-boat furnishes the most striking example in this respect on account of the small resistance with which it glides and is said to attain speeds of 60 to 70 miles per hour in winds blowing but half as fast. The principle and the mathematics of this have been amply demonstrated by others and may be found in reference works. The principle of the wedge furnishes the explanation. The horizontal resistance of the water, or ice, furnish in the case of boats the fulcrum by which they are wedged forward by the force of horizontal-flowing air acting obliquely on the sails; whereas in the case of the soaring birds gravity in exactly the same way becomes the fulcrum against which the momenta of vertically directed air masses act on the wings to urge them forward in horizontal directions at speeds greater than the vertical velocities of such air.' The difference between the speed of the air and moving object in the respective cases is proportional as the sine of angle of inclination of sail or wing is to its cosine, if considered as flat surfaces and in absence of friction and other resistances. And with these latter eliminated, it is a matter of mathematical certainty that the boat or bird could acquire infinite velocity (in an infinite time) in any angular direction horizontally to the moving air no matter how slow the latter. It will be seen immediately, too, that this in principle amounts to saying that a body gliding down an inclined plane without resistance would acquire unlimited velocity due to the acceleration of gravity, no matter how slight the inclination; thus, if for such inclined plane we substitute a rising atmosphere, and for the body gliding down, the bird with wings held at an inclination to glide down, we have an (imaginary) case of a body accelerated indefinitely without losing position, and it is a matter of choice, according as it is looked upon, whether gravity or the rising air in this case furnishes the propellant, though the latter is obviously the only true, gravity being merely a static force serving to translate part of the vertical force of moving air into a horizontal direction. With resistances introduced, as they must, it is easily explained why a boat as the wind rises soon loses out; why also a buzzard in winds of hurricane force is outstripped is equally plain, considering our fundamentals.

Now, there is this point to be observed in this connection: Vertically directed air on the whole is proportional in velocity to the horizontal whereof it is component, and the energy of air bears direct ratio to the square of its velocity; accordingly, as the wind increases in velocity its ability for work increases as the square. Were it not for limitations to be enumerated, the speed of the bird due to vertical impelling forces would then be the greater in proportion as the wind blew faster. Skin friction increases at a rate somewhat less than the square, according to Zahm's experiments. Restitutional resistances cannot vary with speed, being incident to the support reaction which is constant. Other minor resistances may increase as the square of the speed. These in themselves and combined, therefore, stand as no hindrance to an indefinite, geometrically increased speed. One limiting factor is the disruption of the air above the point prescribed by the characteristics of body form and the surfaces for a critical speed. Above that limit the resistances increase at a fearful rate. But the most decisive circumstance is this: that the fulcrum available for the bird—namely his weight—is not sufficient for the increased driving force necessary to propel him fast enough, with a reasonable angle of drop, to make headway against winds of hurricane force, though the available energy is there and quite sufficient. Could he by some mysterious means increase his specific gravity to conform to the impelling force and also increase the length of his body and alter the speed harmonies of his surfaces (making them shorter, broader and of easier curves, which he can do only to a limited extent) he would have it in his power to advance with reference to the ground, against the wind or in any direction, in proportion faster as the wind blew, and no matter how fast it blew, spite of the resistances. Thus in a hurricane blowing 80 m. p. h. such wonderful bird might glide along nicely at 240 m. p. h. air-speed, or thereabouts. Our actual bird, however, is a compromise; he cannot put on a new pair of wings to conform to weather conditions. His body and wings are permanent fixtures adaptable only to average conditions within as wide limits as biological principles allow. Hence he cannot perform as we can in theory and (who will say!) maybe to some extent in practice.

It might be of some interest to observe how this principle finds application in nature. The gull and wild duck are quite extreme types for comparison. The latter, who uses his wings for propulsion under water more than for aerial journeys, one should not expect to be able to soar by atmospheric energy alone; yet, why not, if the above is true? On account of small wing-spread compared to weight it must in all cases maintain great air-speed in order to obtain sufficient support-reaction. On calm days it takes to the wing only with great reluctance, stays up but short periods and flaps its wings with the utmost rapidity of which capable. No more expensive apparatus than a pair of ordinary eyes and retentive memory is necessary, however, to determine the fact that as the wind increases the number of flaps per unit time in his case decreases, but particularly the amplitude of the wing-beats, and the greater the wind, the more readily he takes to the air on the slightest provocation and the further he flies from points of danger. In very stormy weather his flapping is intermittent and it is no uncommon thing to see species of his kind actually soar for considerable distances without any muscular effort whatever. The gull, who in ordinary weather soars very comfortably and is on the wing nearly all day, at such times finds it "hard going" and hugs places along shore lines and cliffs where it may doubly benefit from atmospheric power and avoid its direct fury. Nature has evidently adapted its wings to average conditions, and that means relatively slow speed; hence when conditions call for far greater speed it is at a disadvantage. Were it a question of a long distance speed contest between gull and duck, it would altogether depend on weather conditions which one would arrive first. On a very calm day the duck would not arrive at all and on a very stormy day the gull would cross the line hours after the former, if it got there at all without rest. Indicated from this is the conclusion that the aeroplane that wins the Gordon-Bennet speed contest of the future, and holds the record for all time, will be of the type employing flapping as well as propeller drive, and whose operator on the day the event takes place duly proportions ballast (sacks of sand or lead) and surface extensions to the wind speed prevailing. Speeds around the 300 m. p. h. mark may be expected for such contraptions, though they will not cut corners very sharply. **Le temps decouvre la verite.**

VIII. GRAVITY AND MOMENTUM AS RULING POWERS IN SOARING FLIGHT—Resume

In soaring flight we have met so far nothing but the application of old and well established physical laws. Nowhere has it been necessary to postulate "unrecognized principles" as a guide to the understanding. But, unlike the workings of something inorganic, as a steam engine, planet in its orbit, etc., here we have to do with the dynamics of something living and able to introduce complications that in a way seem to upset basic rules. The guiding rules nevertheless are easily discernible and from these no deviation may be had. The will of the bird is indeed supreme and controlling, but only within the restrictions of the mechanical principles pertaining to its art. These principles have been laid down with such rigor as thought necessary. A few finishing touches remain to be added in the way of an **en semble** view of essential principles. Couching these in fanciful terms may be permissible considering the range and beauty of the subject.

Gravity and momentum, it will appear from what has gone, are the ruling factors in animal flight. Two main systems have been recognized—the air on the one hand and the bird on the other—whose tendencies are essentially hostile. In and between these conflicting systems we may truly enthrone gravity as king and arbiter and place beside it, as helpmate, momentum as the queen. The king as an ethereal master element of the RULING SYSTEM—the bird—guides, compels and enables HIS SUBJECTS—the wings—to act in gathering sustenance from the CONTROLLED SYSTEM—the air: the queen, as complementary element, ever urging to action, a steady consumer but indispensible—the eternal feminine—squandering energy as collected, ever insatiable for more; the power behind the throne without which the system must come to an end. As with the planets in their orbits, so here: these two entities are complementary, supreme and indispensible: though above all we must place the will of the bird.

Of the two, the queenly element is the simpler in function. Except as noted under "c," Chapter VI., her office is to maintain the support reaction and stands for the horizontal speed of the system. This is resisted, and thus the conservation of the momentum becomes a matter to which everything else is subordinate in the ruling system. Her relation to gravity is intimate. Not being well constituted for saving, any excess energy gathered within her fold, if not wilfully wasted, is transferred to the gravity reservoir, which transfer is automatic; conversely, if a deficiency occurs, gravity supplies the need, also automatically so long as the equilibrium is maintained.

Gravity is king. Ruling with absolute consistency and uniform action, yet his functions become split up into many. In and to his action everything that relates to the mechanics of soaring flight may be embraced and referred. Epitomized his functions are:

(i) to establish a positive stress and tension of wide range in the flexible wings and their elastic connecting parts, necessary in order that negative forces of the air may be evaded;

(ii) to furnish the constant resistance, or fulcrum, for the application of the driving power essential for sustentation, thus, by indirection, defeat his own tendency to pull the bird to the ground;

(iii) to act as a reservoir for surplus energy derived from any source whatsoever, and as a steadying element conserve the momentum at the most economical rate;

(iiii) to load the system with energy derived from larger upheavals of air masses and, in co-operation with its queen, make this advantage permanent by evading possible negative effects of large declines of air.

On the one hand we behold an elastic system, the atmosphere, charged with enormous energy but ever ready to absorb more; on the other a similar elastic system, the bird, parasitic and sparcely charged, ever ready to turn transactions with the former to its advantage. Both striving, as it were, to undo the other, the situation is one of conflict. The kinetic energy of the atmosphere must first pass into a potential condition before it can do work and be absorbed by the prasitic system and the latter must be properly receptive to its influence, considering the evanescent character of the air and its forces. Thus only "on condition" will the atmosphere separate with any of its contained energy, while, per contra, it greedily absorbs unlimited quantities howsoever presented unless such energy is suitably insulated against its all-devouring tendency. Therein the **crux mathematicorum** in the conflict —how to figure that the bird against such apparent odds comes out victor and with a balance in its favor.

Carried to ultimates, however, the whole conflict resolves into an interchange of momenta and effects between the two systems in which there is in the long run no gain or loss to one or the other, except as the high-grade energy of the air is debased in doing the work imposed on it, leaving in the wake of the action, as an ash, increased entropy. But as one essential condition for the accomplishment of the bird's will, namely indefinite, free transportation to any desired destination, its means must be in thorough accord with the medium that furnishes the transportation—that is, its wings must have mechanical properties akin to, and in harmony with the properties of the atmosphere, viz., **lightness** and **elasticity** closely equal to the latter. This given, the conflict becomes mild and in favor of the bird who may absorb from, or emit energy into the atmospheric ocean as best serves its ends.

If there is one certain moral to be read into this work, I hope it is this: that gravity while it can act as an enemy—as it is seen to do every day at present by displaying its ferocity to a horde of groping-in-the-dark experimenters—is in fact the most intimate friend a bird has. By cultivating a better understanding with it, it will also prove the most reliable ally and friend of human flyers. It only acts as an enemy because of the unstable equilibrium of the atmosphere; but in this itself is discovered a potential source of energy that only requires to be tapped in the right way to yield unlimited quantities, and which, moreover, as a necessary corolary to its utilization—and this most significant—nullifies the hostile tendencies of gravitation. Upsets and breakage of wings in the air will become a thing of the past once the mechanics of bird flight is understood and applied.

IX. ACCESSORY REQUIREMENTS

It does not come within the purview of this limited work to treat of these in any detail, but a few hints are thought desirable to show certain connections and lend further color and proof to the subject matter proper. The accessories to which reference is had are (1) muscular power and its application, (2) means for maintaining equilibrium and direction (steering).

(1) As to muscular power, various lines of reasoning and estimates render it certain that birds, on the average and in the daily run, have no more muscular energy at their disposal and to squander for transportation purposes than the average non-winged animal of corresponding size. Their muscles work on the same principle as those of other warm-blooded species. The internal organs manufacture from the food the chemical elements necessary for combustion and generation of power (glycogen, carbons, oxygen, fats, etc.) The blood transports these elements to the muscles and its office is also to carry away the ashes of the combustion, "the poison of fatigue," for elimination. The vascular system is physically and mechanically limited in this action: cannot be conceived to be much more efficient in the case of birds than in other animals. Of the total energy of the glycogen, etc., supplied the muscles and stored in the tissues, hardly more than 70 per cent can be transformed by combustion into effective work, heat being one of the accompaniments of muscular activity and causing dissipation.

The pectoral depressor muscles of birds, however, are differentiated by certain internal characteristics from those used for locomotion by bi and quadrupeds restricted to moving on the solid ground. These features are (a) larger valvular capacity, so that a relatively tremendous amount of energy can be expended in a short period of time for working the wings; and (b) a peculiar elasticity, i. e., the muscles are normally in a state of static contraction independent of an innervation current, so that to produce flexure power is required. This power is evidently supplied partly by the elevator muscles (though they are very small and weak) and partly by peculiar exterior and intertwined muscular tissue superposed, in a way, on the very elastic main depressors so that by contracting upon and squeezing these elongation and flexure is effected. A more powerful down-stroke is thus accomplished, the energy for which has been partly accumulated in the elastic tension of the depressors during the up-stroke, with the concomitant advantage that the energy output is more evenly generated from the elements in the tissues. This merely suggests the ingenious and most appropriate apparatus nature has provided these animals with, who only need spend energy in great amounts on occasions, as when a burst of speed is necessary, and for starting from a dead stop under various conditions. The up-stroke is effected, however, in the normal run, mainly by the reaction of the air; under many conditions wholly so. It maybe also that these pectoral muscles have a limited reverse action, similar as certain electrical engines that run as dynamos and motors alternately under required conditions. This would be an advantage but would be difficult to determine, if so. ,

For the one who has understood how atmospheric energy becomes available and is utilized as a drive in bird flight, there is little to be told concerning the mechanics of muscular action to this end. By reversal, these drives are of course identical. If a sudden atmospheric impulse moves the wings up and a sudden muscular impulse moves them down, what's the difference so far as effect is concerned? And if atmospheric movements directed downward have no negative effect, why should the elevation of the wings in muscular flapping have any? The inertia of the bird acts as the fulcrum for the application of the power while its weight and momentum are the distributing forces. In no way is this different from the selective action described in Chapter VI. As much as the system of flexibility of the wings is necessary in the application of muscular power, as much is it essential for muscular action to render it simple and automatic.

Muscular power is for the larger soaring birds merely a convenient auxiliary for getting over occasional "bad places" in the air and when the available atmospheric impulses fall below a required minimum point in number and strength. It is indispensable in getting a start, for checking momentum in landing, maneuvering in quest of food, against prey, enemies, and for playful purposes; never is it their main reliance. All birds, bats, insects and even flying fishes use atmospheric energy more or less, since the angular attack of their wings on the air is positive, as contradistinct from that of an aeroplane or kite which is negative. Mode of living determines the preponderance of the receptive (positive) aspect of their wings and, consequently, how much or how little they may profit by air-power in any given case. A duck, for instance, could not exist the way it does if its wings were as large and unwieldy as those of a gull; a compromise has necessarily been affected. And so it may be safely asserted that the same biological law holds true here as elsewhere, that all animals are provided with such specialized means as are on an average best according to conflicting requirements in their mode of living. But this contradicts in no way the proposition that atmospheric power is used concurrently with muscular and to the extent of the positive aspect of the wings of flying animals in all cases. All that needs to be added is that, as indicated at the end of Chapter V, the positive aspect varies approximately as the square of wing dimensions, hence the larger the bird the more it is bound to benefit from air-power in its flight, and that without spreading surfaces proportionate to greater weight.

(2) **Equilibrium and Steering.** Given the necessary provisions for maintaining equilibrium and, under usual atmospheric conditions, the matters of propulsion and support take care of themselves in the case of the larger soaring birds. This was proven in previous chapters. But now, since these matters are so largely automatic, why should Nature impose on these birds constant vigilance in maintaining equilibrium? When pryed into, things are found exactly as surmised. However, it is a matter difficult to demonstrate

on paper within a short compass, and probably this philosophy is getting tiresome. I shall therefore cut the lesson short with the mere hint that the first artificial device for effective soaring will infringe on no patent covering questions of equilibrium and steering heretofore registered in any patent office, though, it is feared, will sadly infringe on that superior, exclusive model—the bird—whose only protection from competition hitherto has been secrecy.

X. ON THE QUESTION OF APPLYING THE THEORY IN PRACTICE

It would be instructive for the one who doubts the possibility of applying the principles herein outlined to the end of ultimate independence of mechanical power in aeroplane practice if he could be made to watch the soaring of the wandering albatross of the Southern Seas. This bird is heavy, specimens having been found said to weigh 25 pounds, and spreading 15 feet between wing tips (probably exaggerated). It is never seen to alight on the water for rest, having a preference for regions swept by trade winds where the water is too rough. It remains on the wing for weeks, nay supposedly for months at a stretch, night and day, and explores countless acres of watery surface every hour of daylight for bits of food floating thereon. It very seldom flaps its wings and follows without the slightest evidence of exertion the fastest steamers going into the teeth of a gale. A sailor told me once he was sure these birds slept on the wing, as he had seen them run into the rigging of sailing vessels in mid-ocean at nights. Accepting this as a fact—and there are good reasons for believing it is, though it may be in a comatose, somnambulistic state they pass the nights—it would imply automatic equilibrium, supplemented necessarily by intervention of lower reflexes so far as concerns steering. The inherent qualities of the birds' wings it is certain take care of the "floatation" proper without conscious effort and without demand on their store of muscular energy.

Examples are instructive, but fact is few draw logical conclusions therefrom. If this is so in the case before us, it is perhaps because of an inate timidity in the face of the problem. It is so much easier to doubt if the means to an end are not clearly seen. We see in the soaring of birds an effect; we see this effect confined not only to the smaller species (as swallows) but that it is the more conspicuously demonstrated the heavier the species (albatross, condor); we discover its causes. The inference is that it has no defined limits for heavier weights and that no sensible reason, founded on more than a "Missourian" inconsequence, can exist for doubting its extension to human needs. Knowledge of the conditions essential to reproduce the effect on the proper scale is what is required. This knowledge given, practical results must flow, though much time, patience, work, ingenuity and evolutionary development may attend the realization to the full extent which the knowledge predicates. The "qualities" on which the effectiveness of bird wings mainly depend has been the main object of demonstration herein, and if their importance as such has been established, the question is, can these qualities be reproduced artificially? Now this, in the author's opinion, depends entirely on success in obtaining the right materials and combining and adapting these according to the perfection of the models so copiously furnished by nature. It must of course be a systematic adaptation and combined with harmonics of form and proportions, otherwise no success can be looked for. This matter I would rather submit to proof by actual demonstration, but this, alas! requires both time and means. (What "wage-slave" possesses much of either?) The moment these essentials come to hand possibly some scrapping of both theories and practice in the conquest of the atmosphere will take place.

Following are some deductions more specifically stated, outlining a **system** of "qualities" for aeroplane construction substantially as found in bird wings. There is nothing in this difficult of realization except as ultimate perfection is called for.

Demanded—

1. That the wings be pivoted at their butt ends for swinging up and down; such swing being restricted in the upward direction by elastic, or elastically connected cables from underneath; similarly connected cables from above serving to uphold the weight of the wings when not in action.
2. That the wing surfaces, so far as practicable, be constructed of the most flexible material to be found and curved fore and aft so as to offer a maximum yielding resistance to pressures from underneath and a minimum to pressures from above, practically as found in bird wings. (Not that it is required that we construct a built-up surface of artificial feathers; an elastic covering like dental sheet rubber stretched over very flexible ribs would do.)
3. That the main beam, rod, or rods, of the planes (corresponding to the bones of bird wings) be so contrived as to have a maximum of elasticity consistent with sufficient strength and to offer, in connection with this quality, a maximum resistance to bending by forces positively directed and a minimum to those negatively directed.
4. That the wings themselves be as light as possible, within limits of a necessary factor of safety (selection being made of the strongest materials combined with refined engineering), so that the elastic responsiveness outlined be brought into play, as far as possible, unrestricted by the inertia of the wings themselves.
5. That the supporting surfaces be rotably mounted on their longitudinal axis; such rotation taking place well in front of stress center, elastically restricted and designed for changing the angle of recession automatically in accordance with the pressure or at the will of the operator. (A factor of safety for the construction anywhere near as great as that required for rigid structures is therewith not called for; but automatic cut-offs may be easily provided in addition so that pressures cannot rise higher than a safe maximum.)
6. That the surfaces have perfect smoothness.
7. That auxiliary power be applied as in bird flight by moving the wings up and down (preferably); thus merely by actuating the under elastically connected cables, the upward swing taking care of itself in connection with the constant support-reaction attending the horizontal progression. For gaining the initial start, the wheels to be actuated by motive power. Wheels in tandem, preferably.
8. That the equilibrium be maintained by an inherent, semi-automatic system of levers and connections, so that the very forces tending to upset would instantly, by mechanical reaction, call into play the proper corrective.
9. That steering be effected by mechanical means on principles substantially as found in bird flight. (With the transition of the surfaces from negative to positive, the systems now in vogue would not be efficient.)

Many more essentials could be added, but the above gives a gist of those which are of primary importance.

One of the developments in aviation (by induction from bird flight) will be a light, rigid harness fitting the aviator's body, contrived for the attachment of the wings; no tail or similar encumbrance; leg muscles actuating the flapping of the wings when necessary; start made from some high point or hill against the wind; aviator's position, prone or upright. It may take as long as it took to develop the motorcycle from its first embryonic condition to its state today to bring such small units to a dependable state of perfection, but once accomplished their cost of construction should be less than that of the motorcycle today. With the production of such apparatus, true "man-flight" would be achieved.